Future opportunities for small-system scan at RHIC

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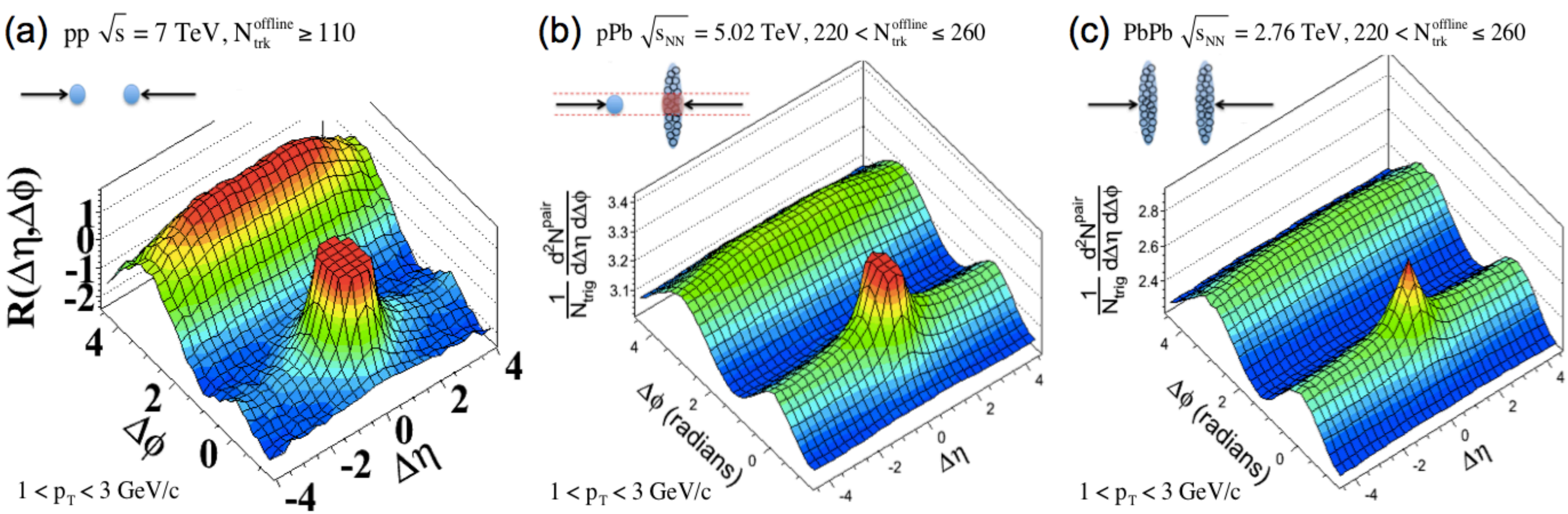
With inputs from Jiangyong Jia, Wei Li, ShinIchi Esumi, Shengli Huang, Roy Lacey, Constantin Loizides, Li Yi, Aihong Tang, Prithwish Tribdey, Fuqiang Wang

2019 RHIC & AGS Annual Users' Meeting

Collectivity in small systems



JHEP 09 (2010) 091

PLB 724 (2013) 213

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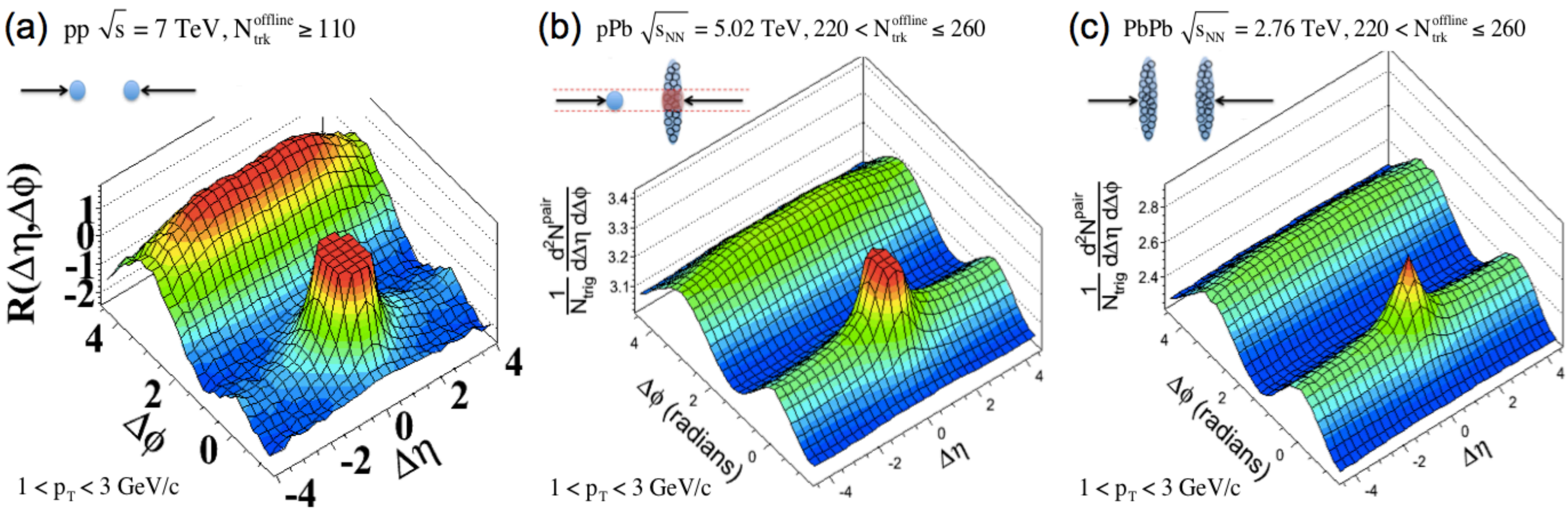
What is the origin of the collectivity in small system?

A small droplet of QGP? Initial state effects (e.g. CGC)?

Collectivity in small systems



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PLB 724 (2013) 213

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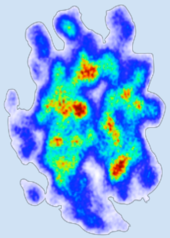
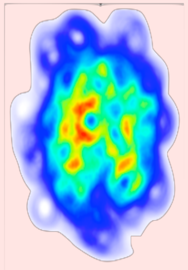
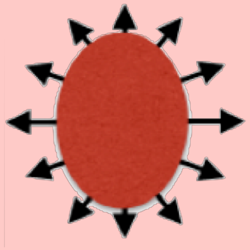
What is the origin of the collectivity in small system?

A small droplet of QGP? Initial state effects (e.g. CGC)?

Not a YES/NO question!

Time-scale for collectivity

Initial state t ≈ 0 fm/c	Pre-equilibrium t<0.5 fm/c	Hydrodynamics t ~ 0.5-5 fm/c
		
momentum anisotropy e.g. mini-jets, glasma	Non-equilibrium transport	Collective expansion

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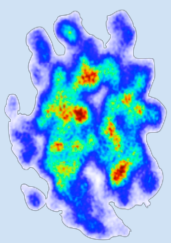
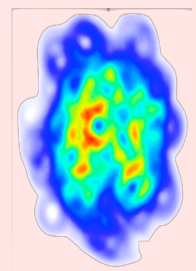
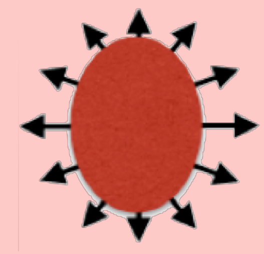
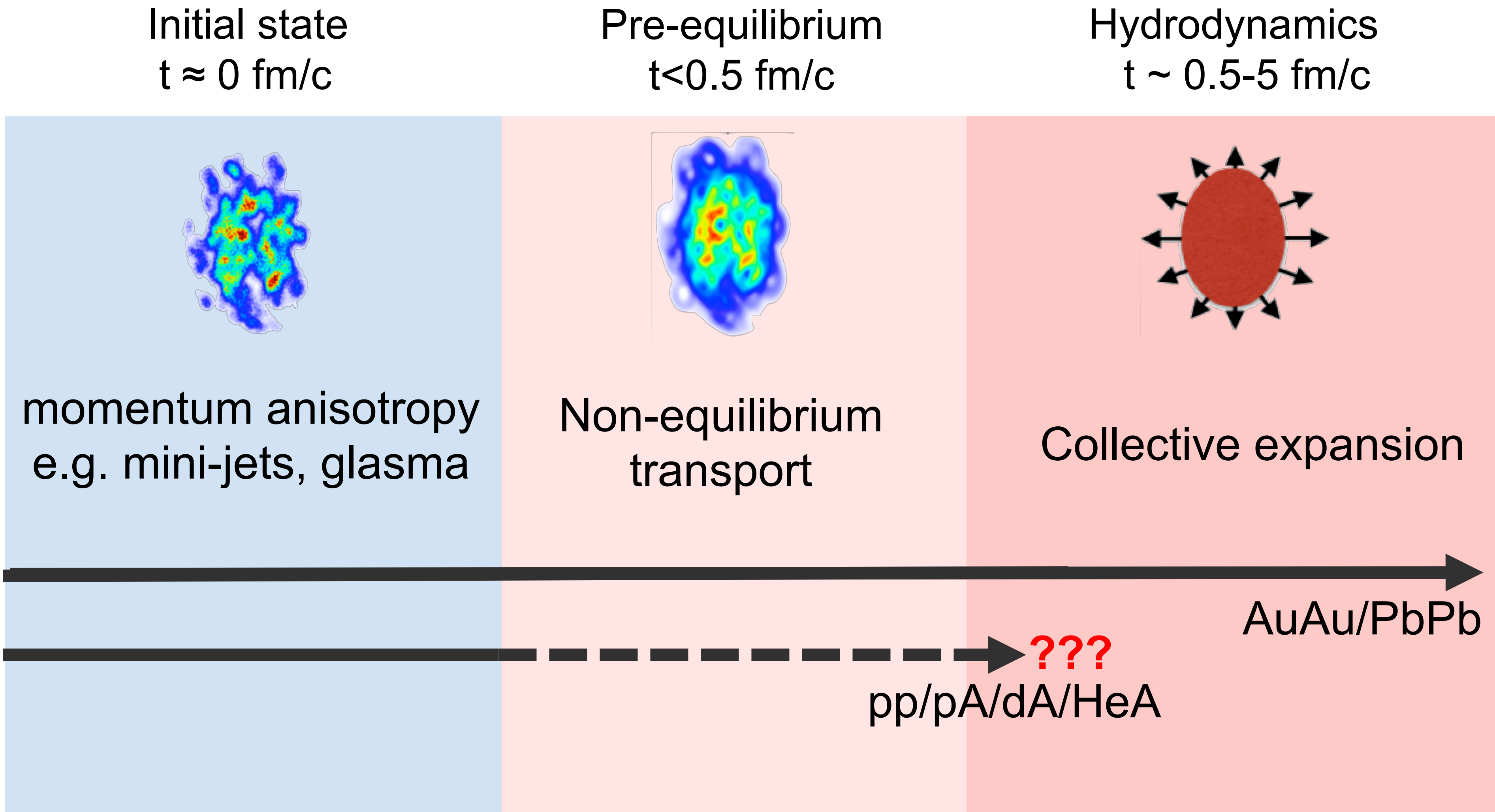
		
momentum anisotropy e.g. mini-jets, glasma	Non-equilibrium transport	Collective expansion **Dominant**

AuAu/PbPb

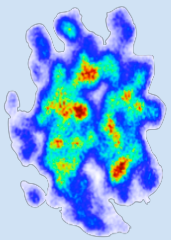
Time-scale for collectivity

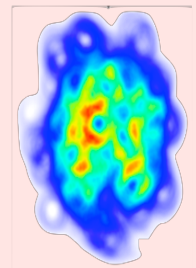


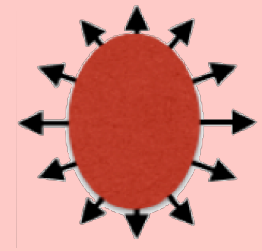
Contributions from different stages in small system?

Time-scale for collectivity

Initial state	Pre-equilibrium	Hydrodynamics
t ≈ 0 fm/c	t<0.5 fm/c	t ~ 0.5-5 fm/c







momentum anisotropy e.g. mini-jets, glasma	Non-equilibrium transport	Collective expansion

Geometry-uncorrelated

Geometry Response

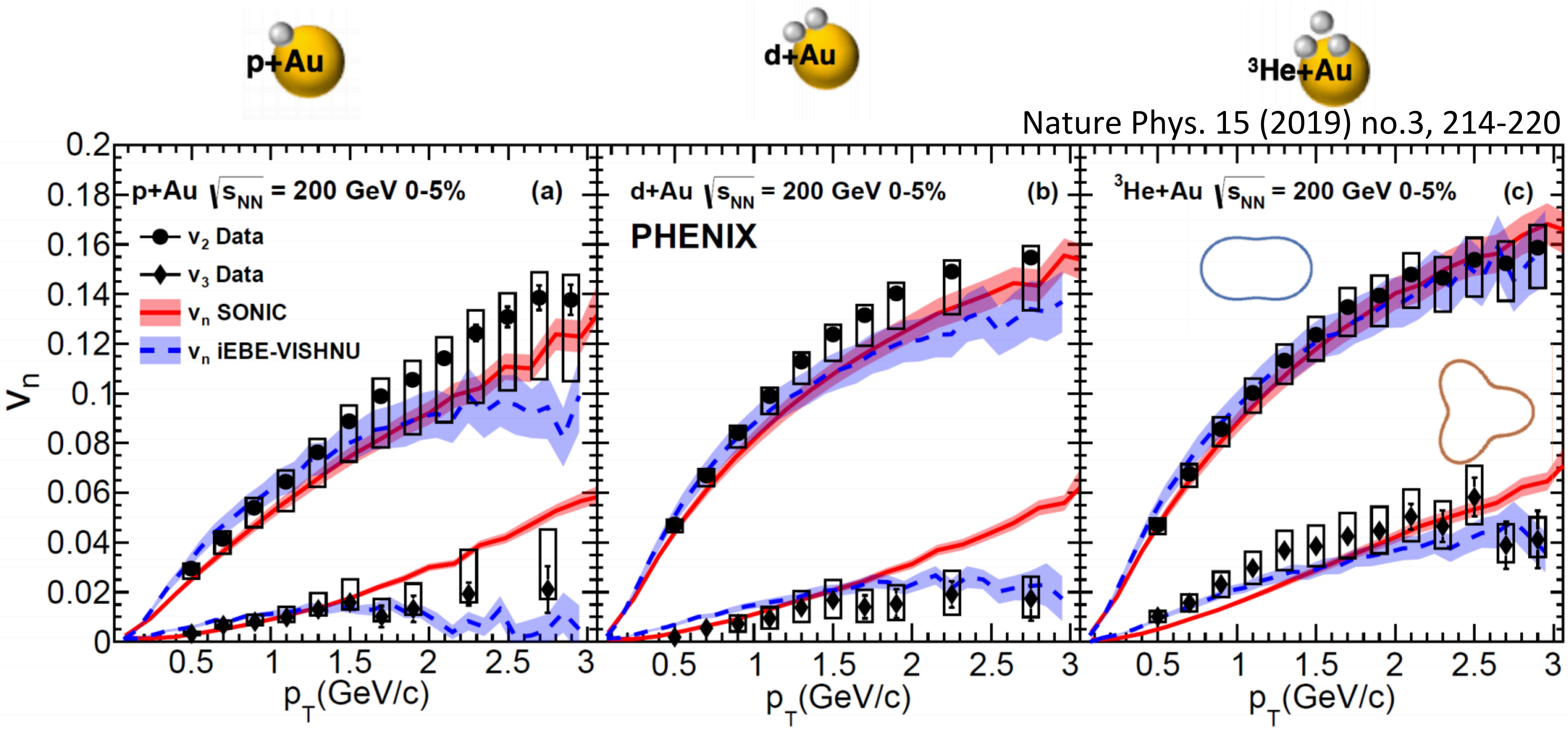
AuAu/PbPb

???

pp/pA/dA/HeA

Contributions from different stages in small system?

RHIC geometry scan



Nature Phys. 15 (2019) no.3, 214-220

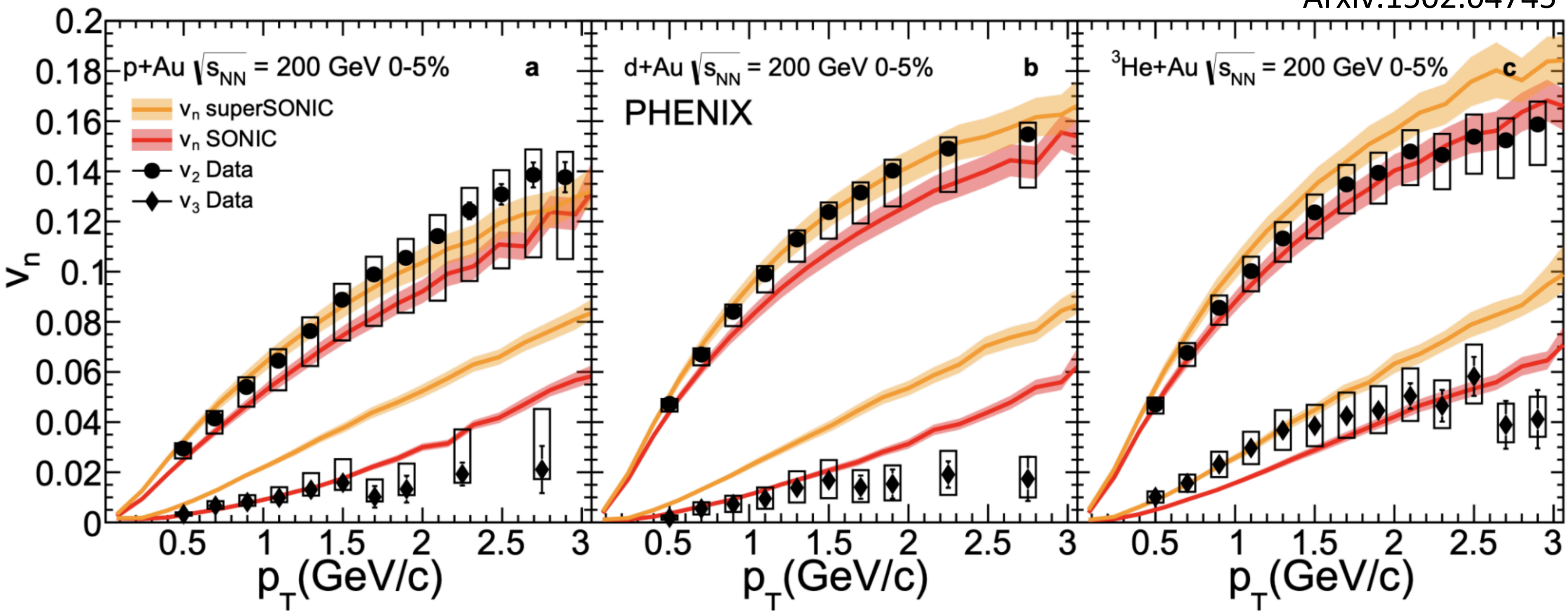
Hydro captures the geometry response

Hard for CGC at this moment[1]

[1] http://www.int.washington.edu/talks/WorkShops/int_19_1b/People/Mace_M/Mace.pdf

RHIC geometry scan

Arxiv.1502.04745



Hydro captures the geometry response

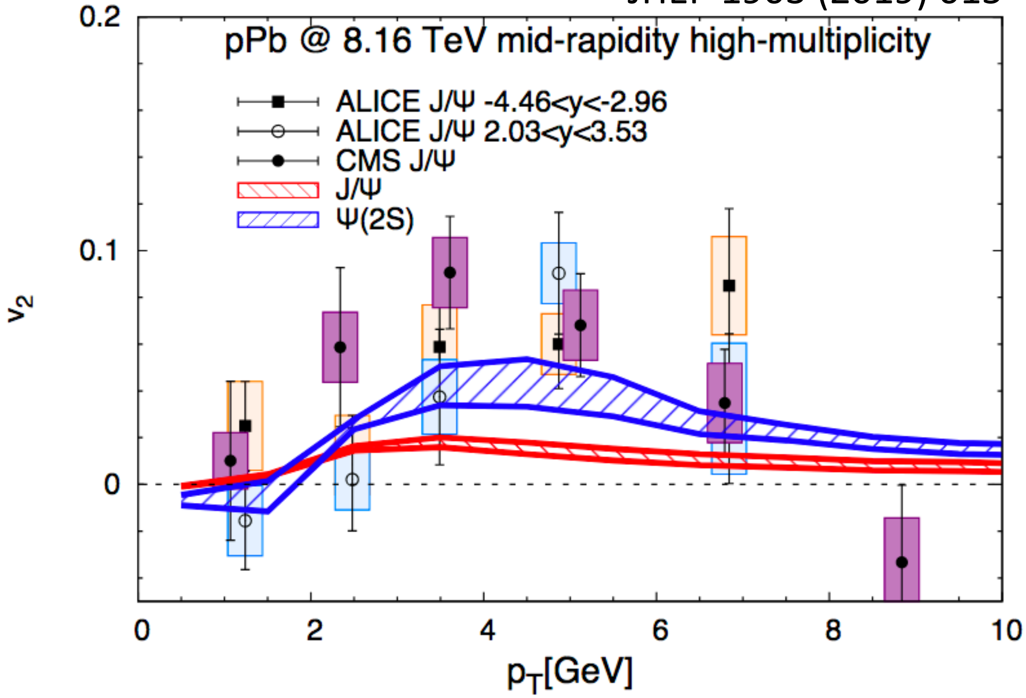
Hard for CGC at this moment[1]

Important effect of pre-equilibrium flow under investigation[2]

[1] http://www.int.washington.edu/talks/WorkShops/int_19_1b/People/Mace_M/Mace.pdf
[2] https://indico.cern.ch/event/771998/contributions/3339235/subcontributions/276910/attachments/1813022/2961981/talk_smallsystems_SHEN.pdf

LHC heavy flavor flow

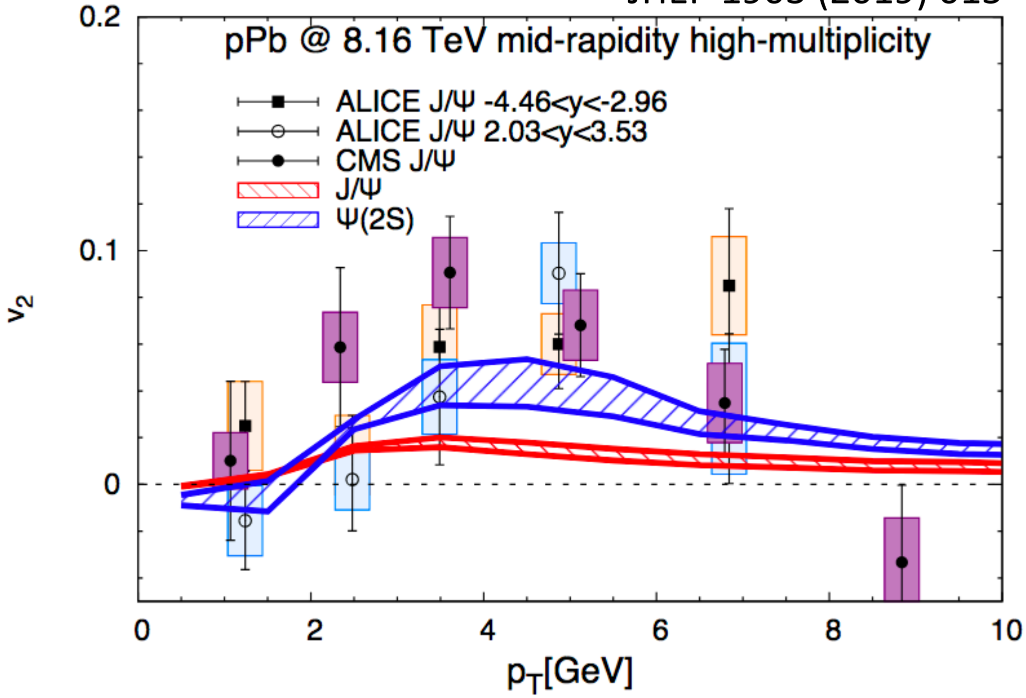
JHEP 1903 (2019) 015



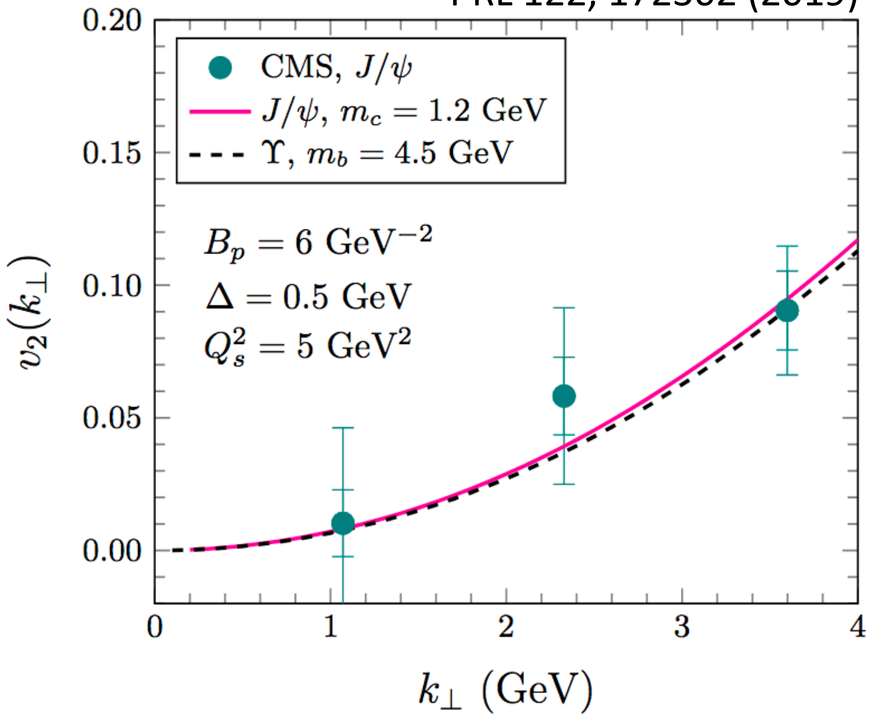
Final-state interaction model fail

LHC heavy flavor flow

JHEP 1903 (2019) 015



PRL 122, 172302 (2019)

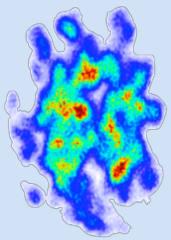
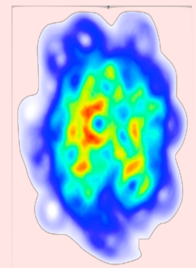
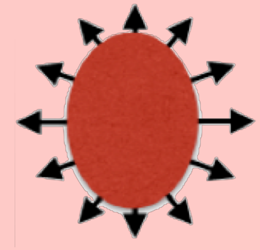


Final-state interaction model fail

Initial momentum anisotropy model works

Initial state interactions are important in small systems

Control different contributions

Initial state t ≈ 0 fm/c	Pre-equilibrium t<0.5 fm/c	Hydrodynamics t ~ 0.5-5 fm/c
		
momentum anisotropy e.g. mini-jets, glasma	Non-equilibrium transport	Collective expansion

Geometry-uncorrelated

Geometry Response

AuAu/PbPb

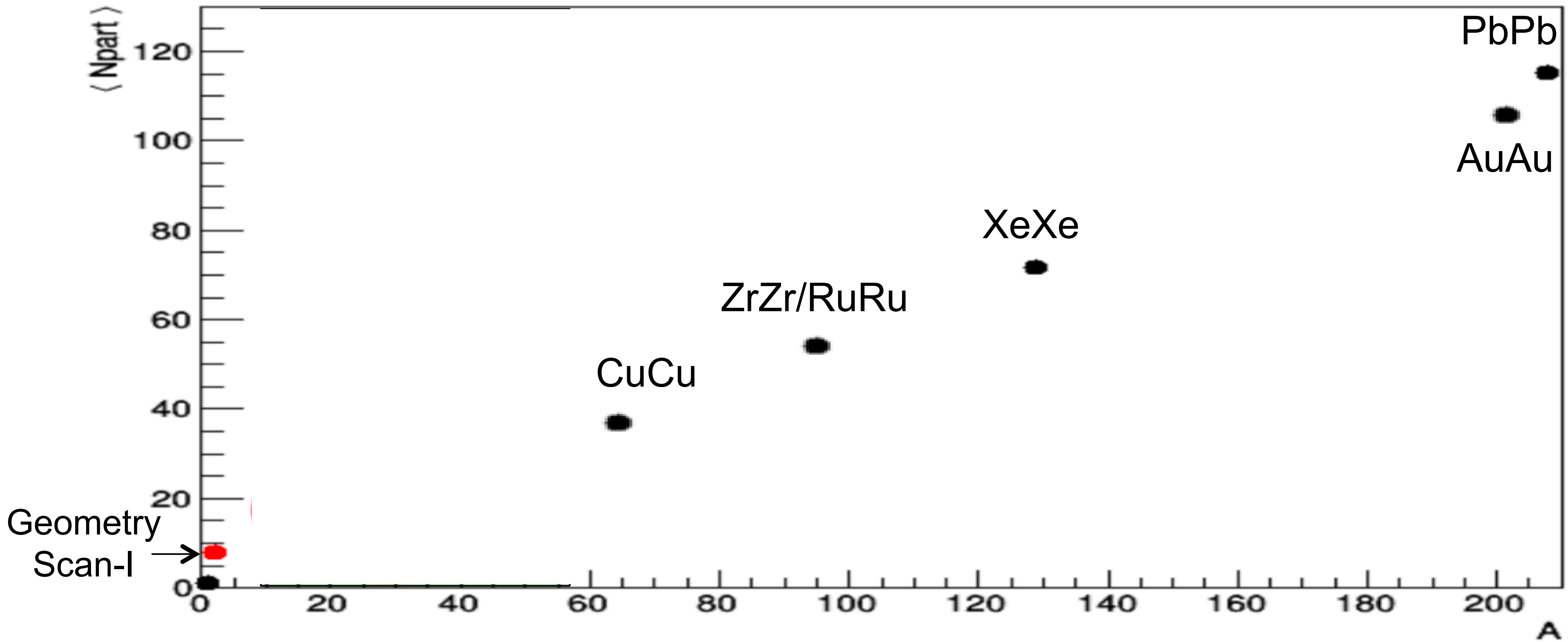
???

pp/pA/dA/HeA

C+C, O+O, Al+Al, Ar+Ar etc.

Extend lever-arm with system size scan

The "gap"


⟨Npart⟩
120
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40
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0
0
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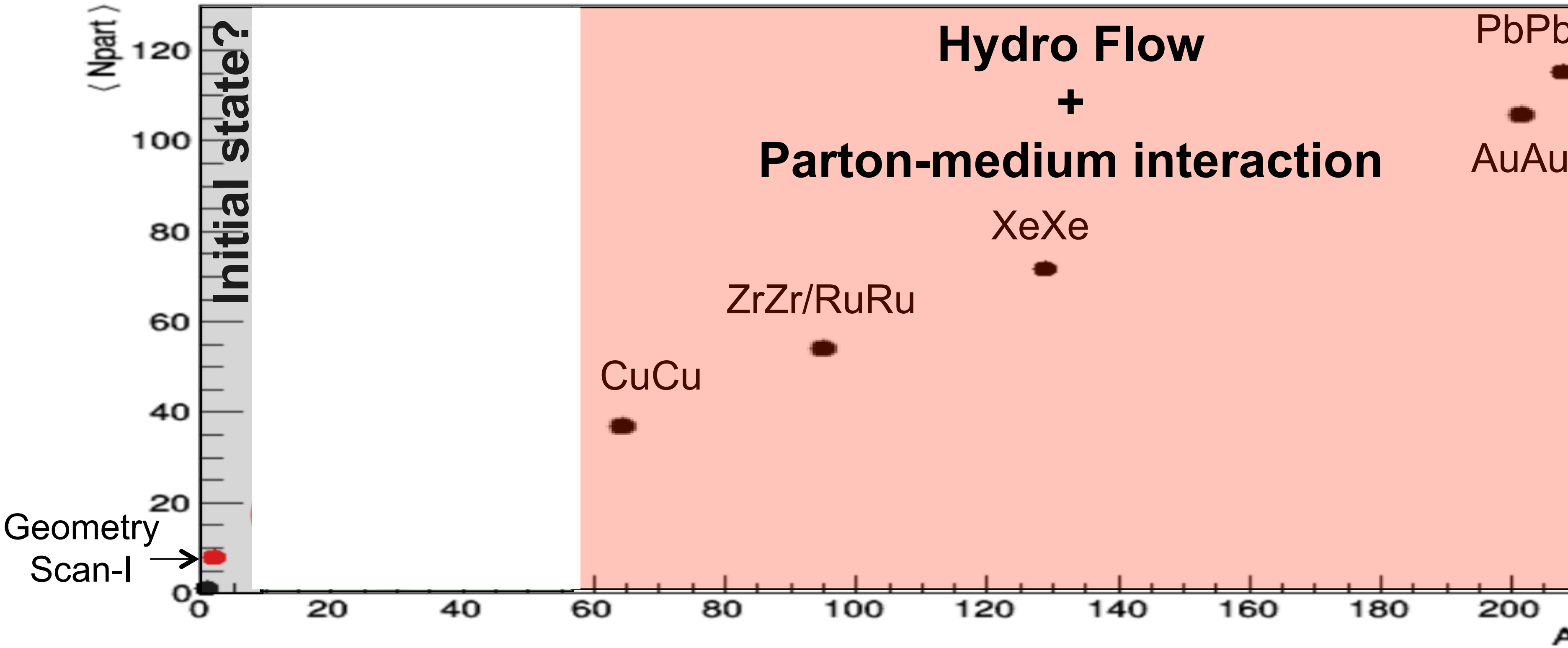
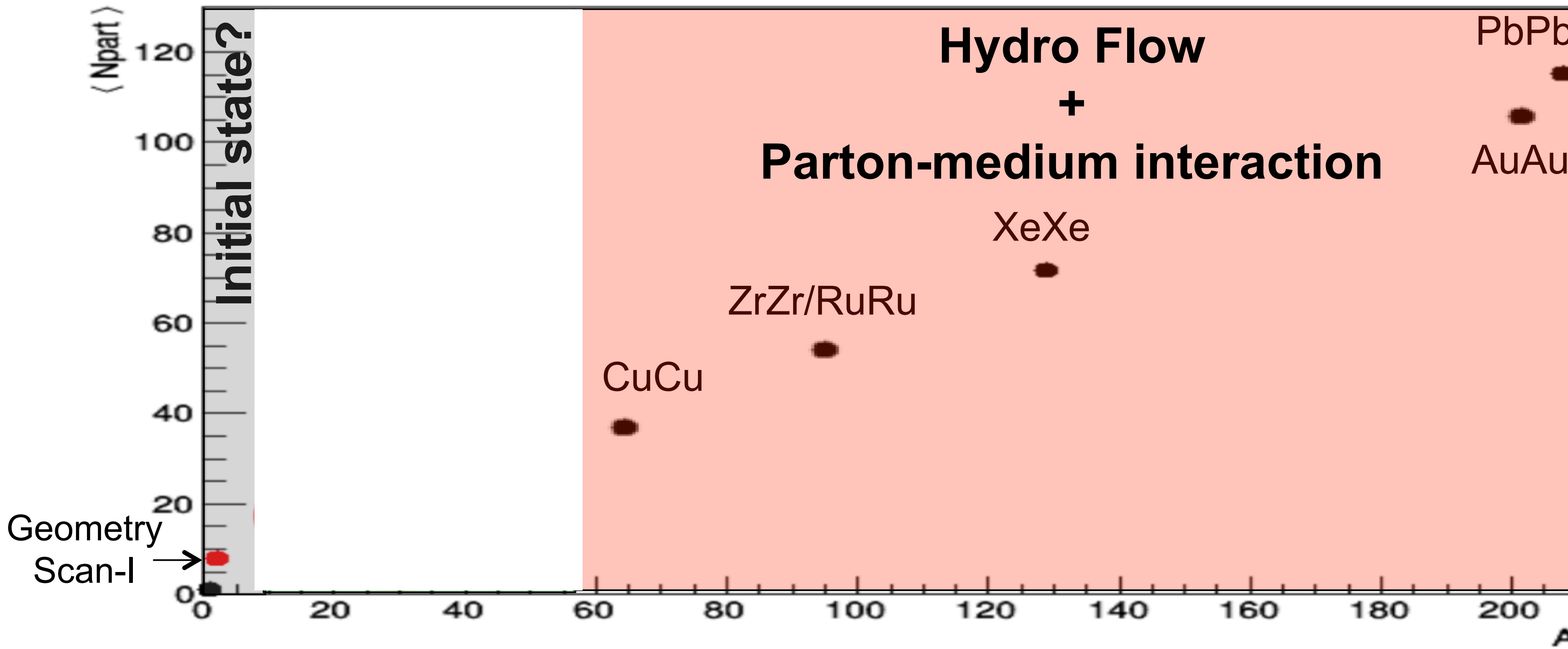
40
60
80
100
120
140
160
180
200
A
PbPb
AuAu
XeXe
ZrZr/RuRu
CuCu
Geometry
Scan-I

The "gap"


⟨Npart⟩
120
100
80
60
40
20
0
0
20
40
60
80
100
120
140
160
180
200
A
Initial state?
Hydro Flow
+
Parton-medium interaction
PbPb
AuAu
XeXe
ZrZr/RuRu
CuCu
Geometry
Scan-I

The "gap"

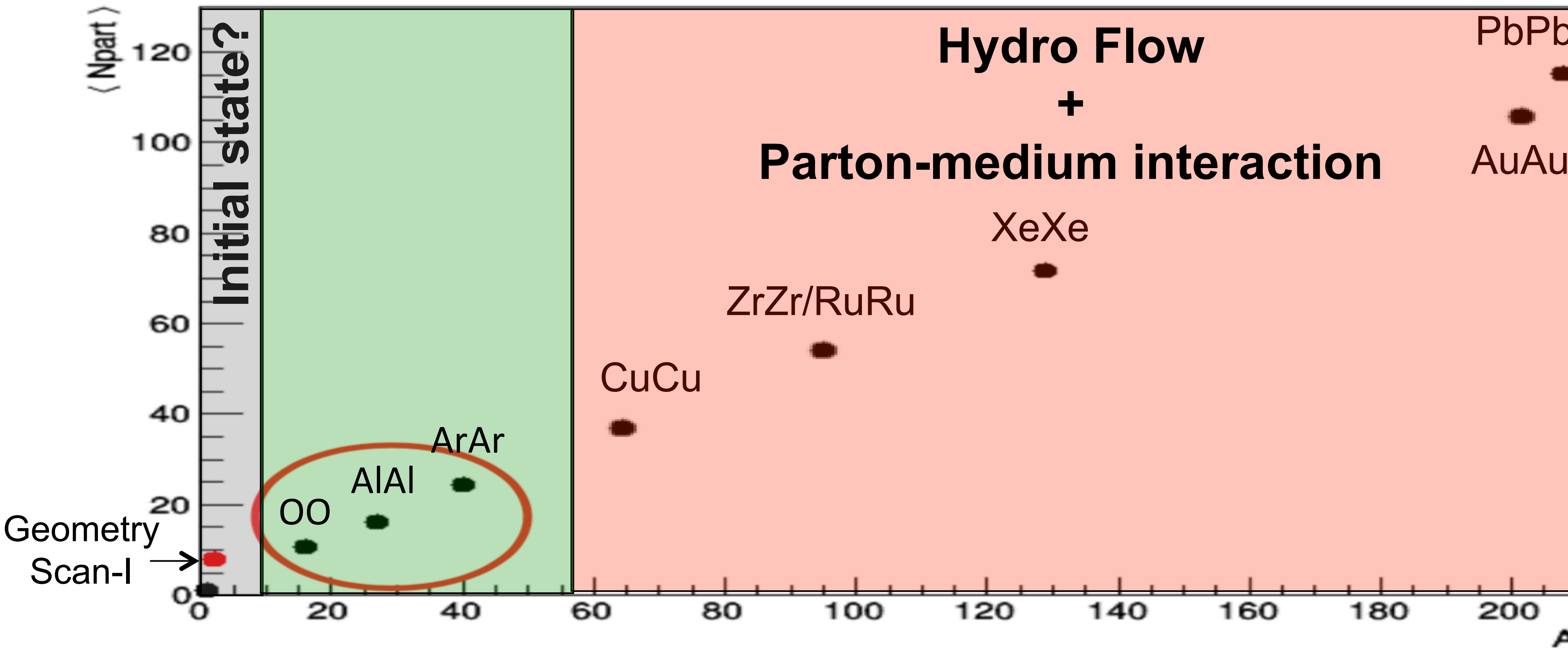


Where initial-state interaction become sub-dominant?

The role of pre-equilibrium vs. hydro?

Turn-on of jet quenching and heavy-flavor "thermalization"?

Bridge the "gap"



Where initial-state interaction become sub-dominant?

The role of pre-equilibrium vs. hydro?

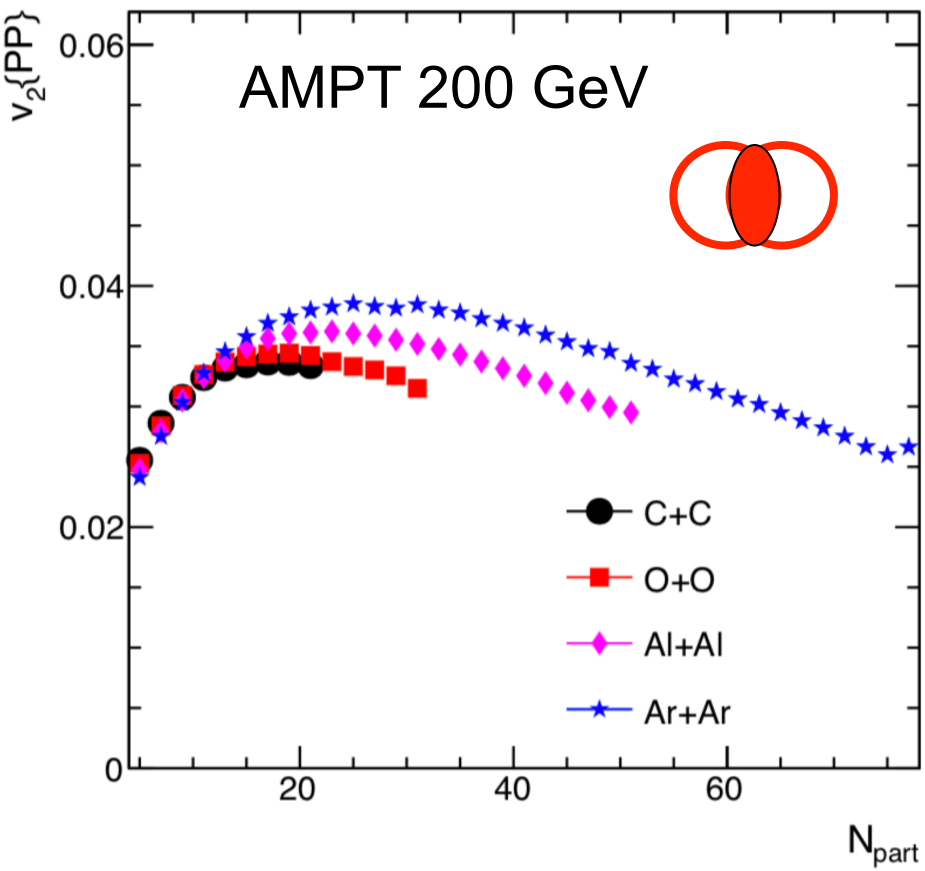
Turn-on of jet quenching and heavy-flavor "thermalization"?

System size scan needed!! Only RHIC can do!!

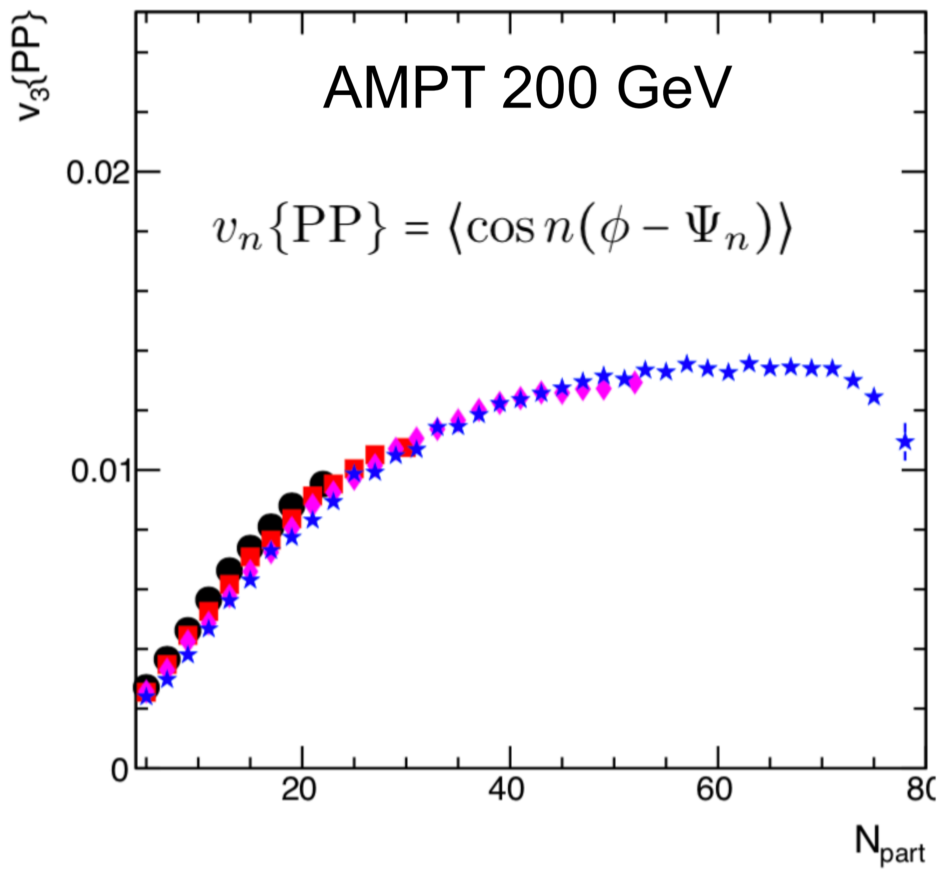
Geometry response of flow

Arxiv.1904.10415

Split due to average geometry



Fluctuation dominant

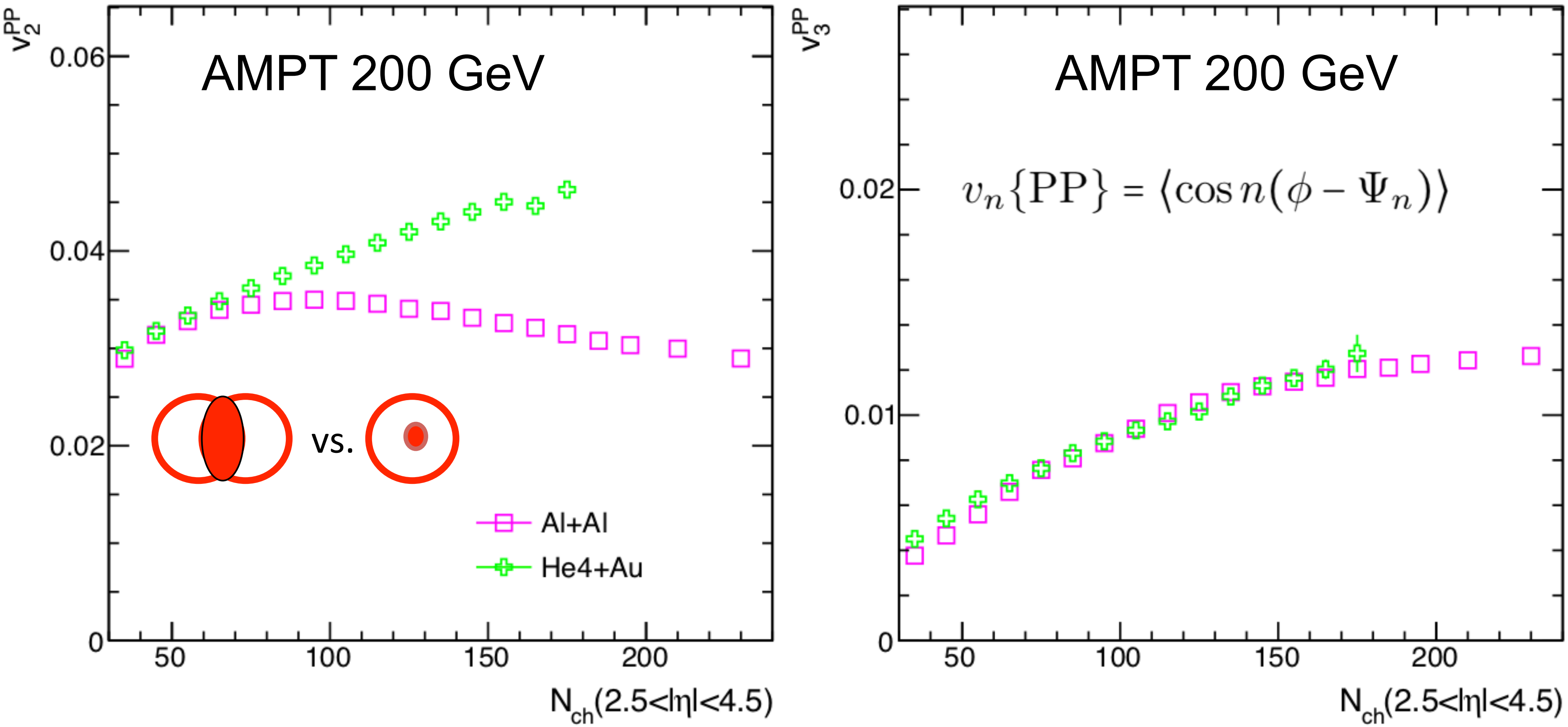


Geometry response of v_2 not expected in initial-state picture

Potential to constrain transport vs. hydro

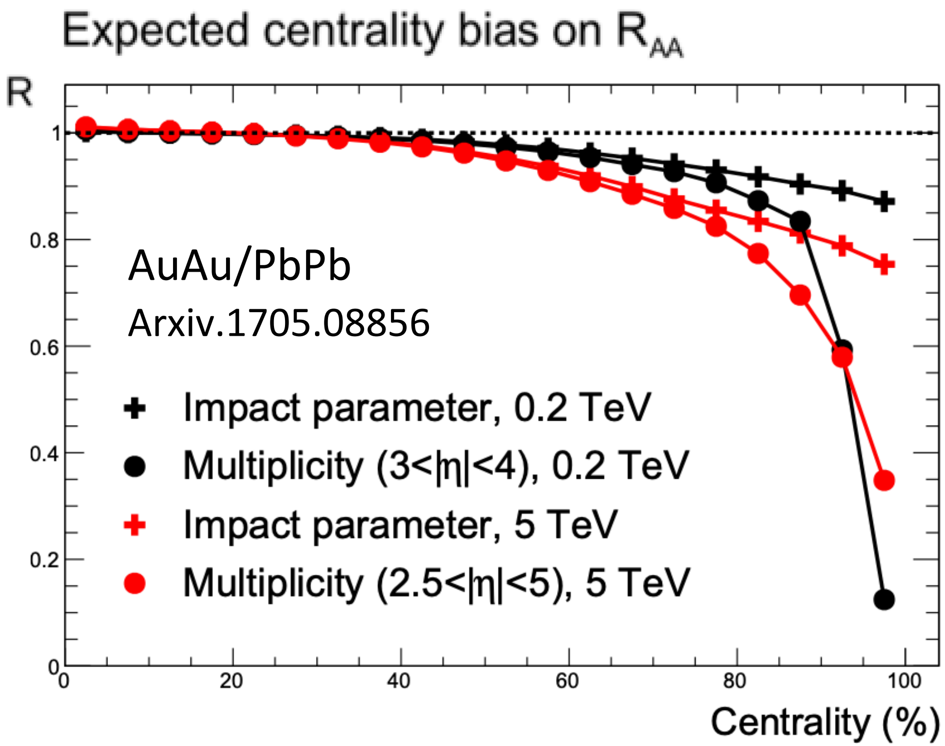
Geometry response of flow

Arxiv.1904.10415



Different geometry response of v_2 in p(A)+A

Parton medium interaction



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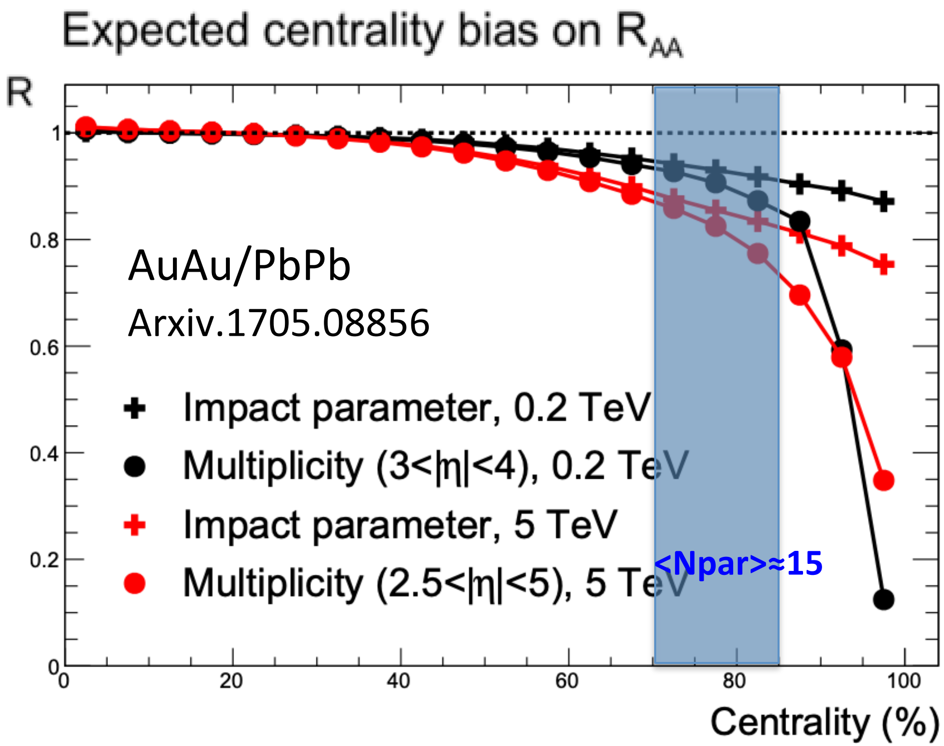
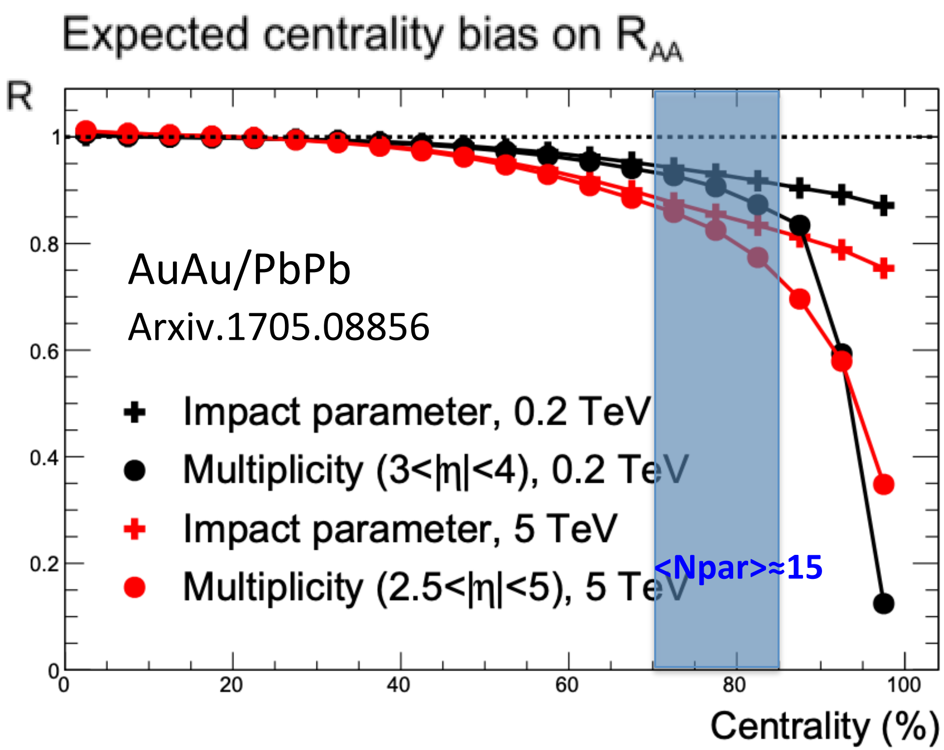
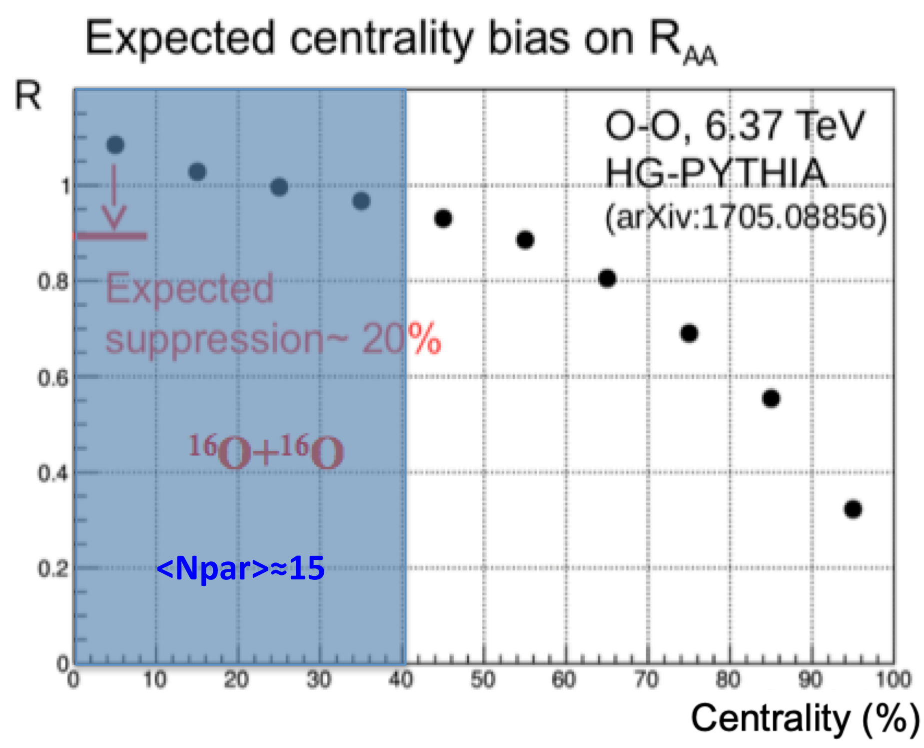


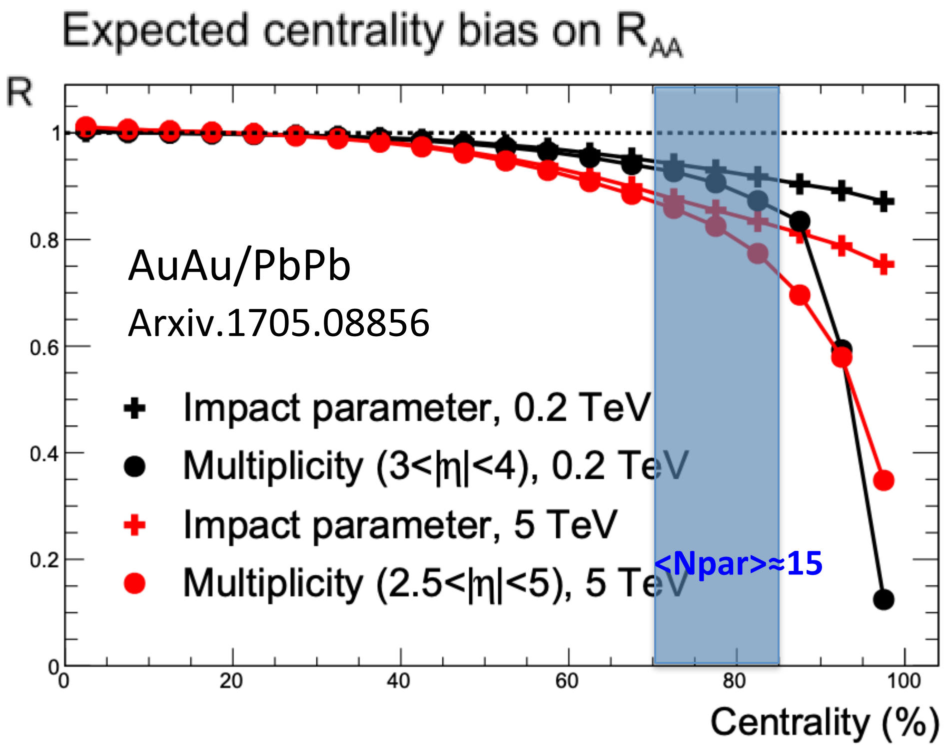
Parton medium interaction

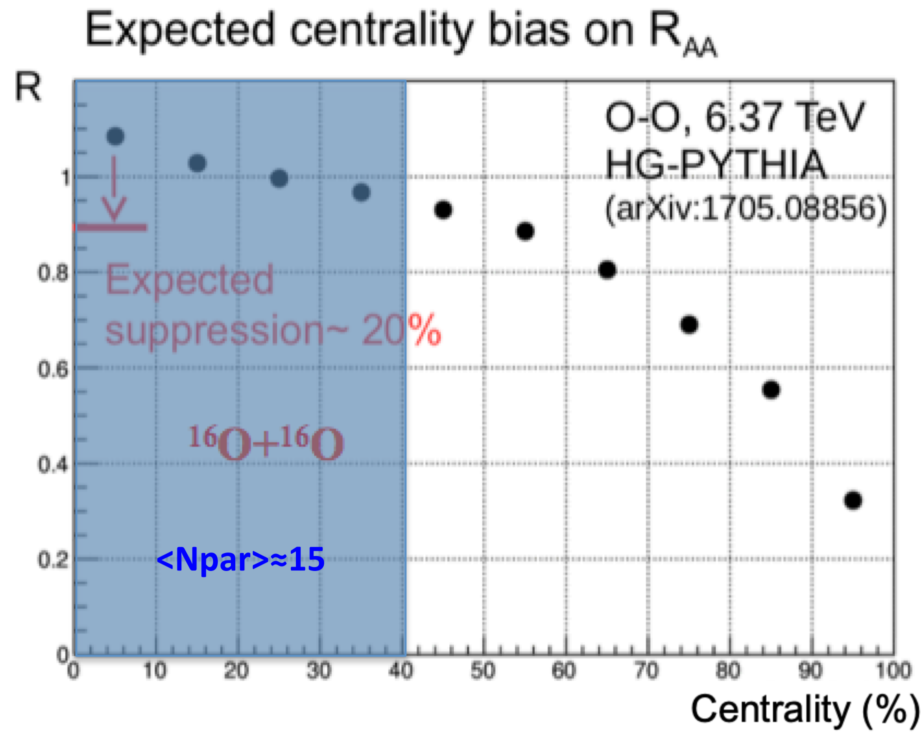




Better control of centrality bias at same <Npar>

Parton medium interaction

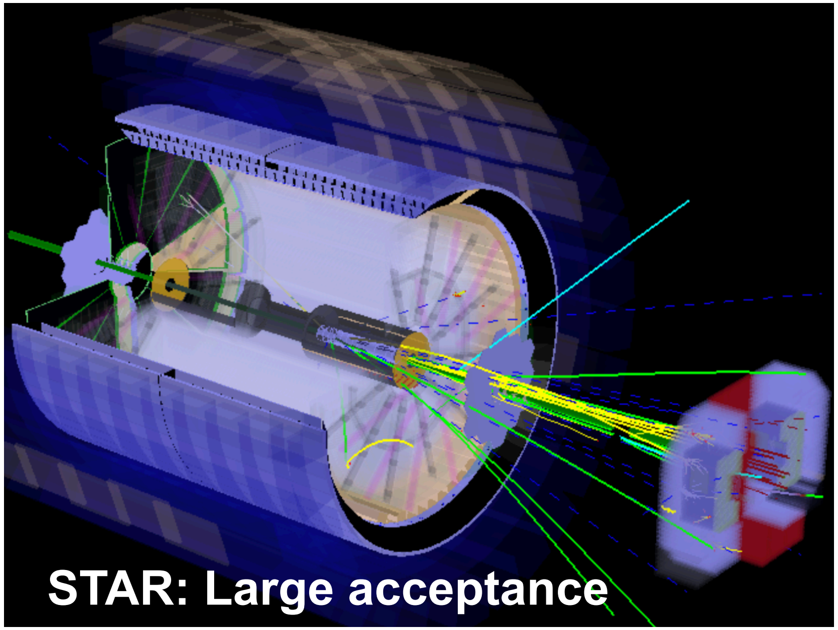




Better control of centrality bias at same <Npar>

The scan -> Same parton spectra with changing system size

Best duo for the scan



Large acceptance & PID from STAR (2019+)

- iTPC ($|\eta|<1.5$, PID), EPD ($2.1<|\eta|<5.1$) and eTOF (2019+)
- Forward upgrade with pT, ET, PID (K_s,Λ,π^0) at $2.5<\eta<4$ (2021+)

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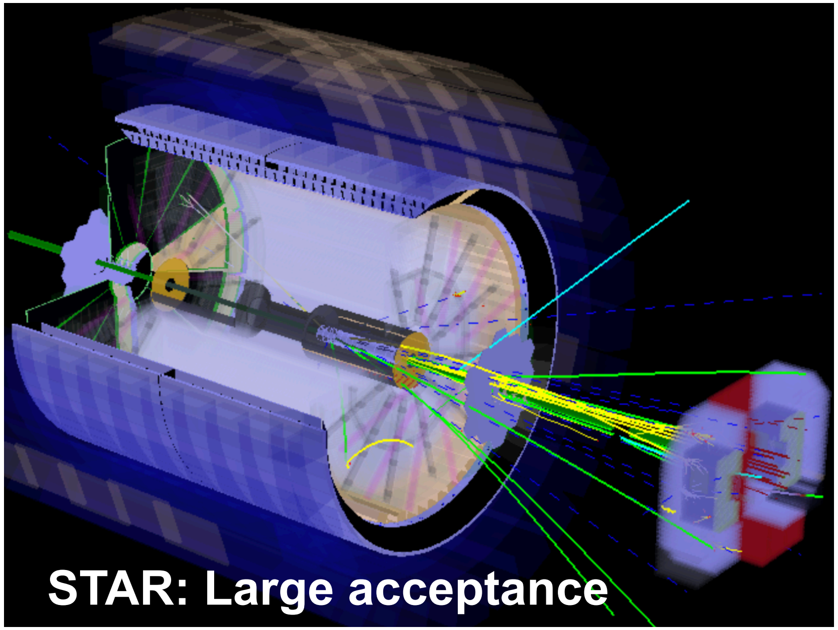

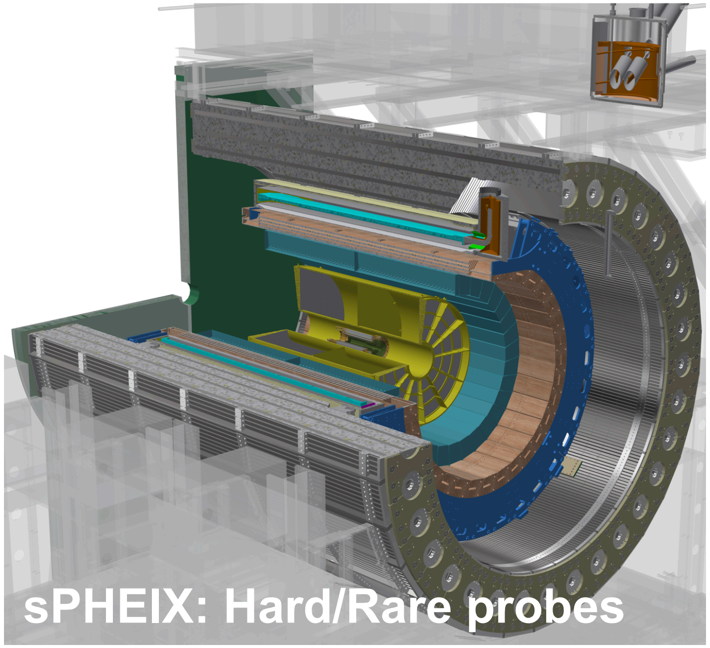

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Hard/Rare probes from sPHENIX (2023+)

- 15kHz DAQ
- EM+HCal

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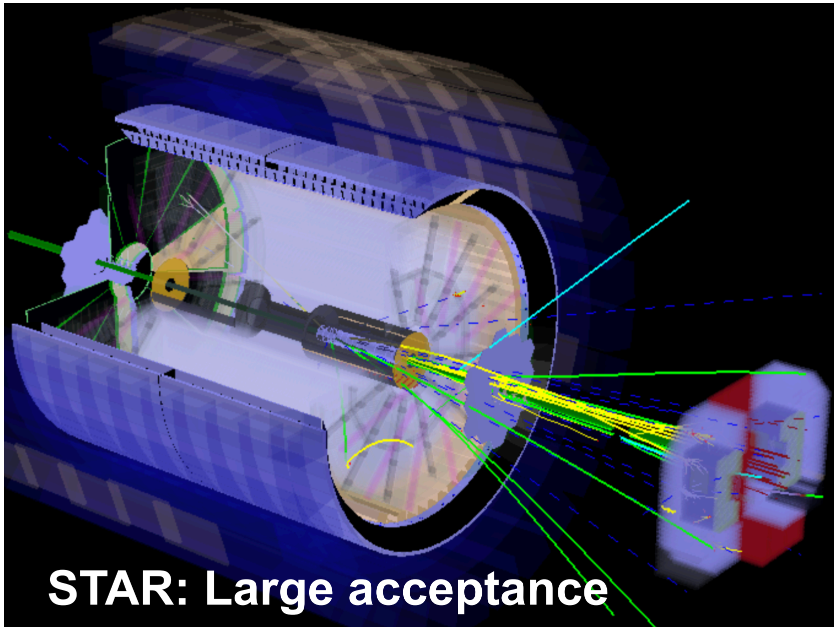

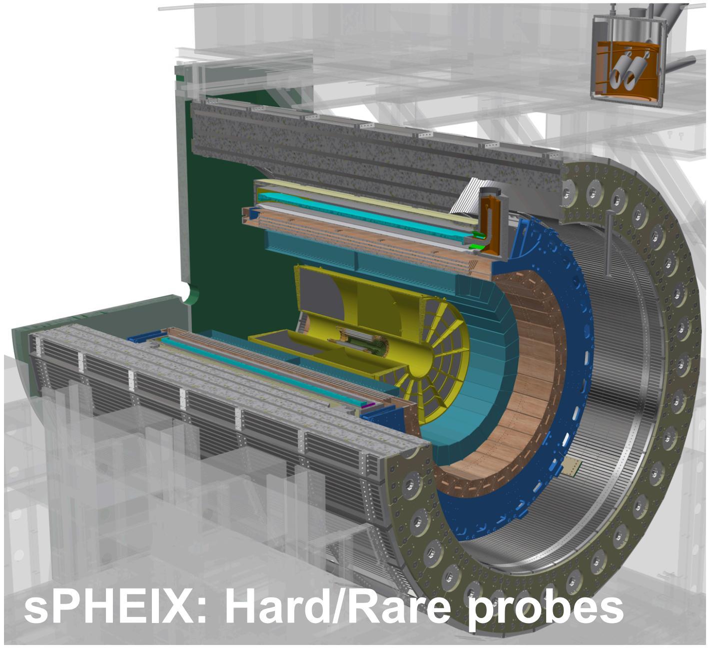

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Hard/Rare probes from sPHENIX (2023+)

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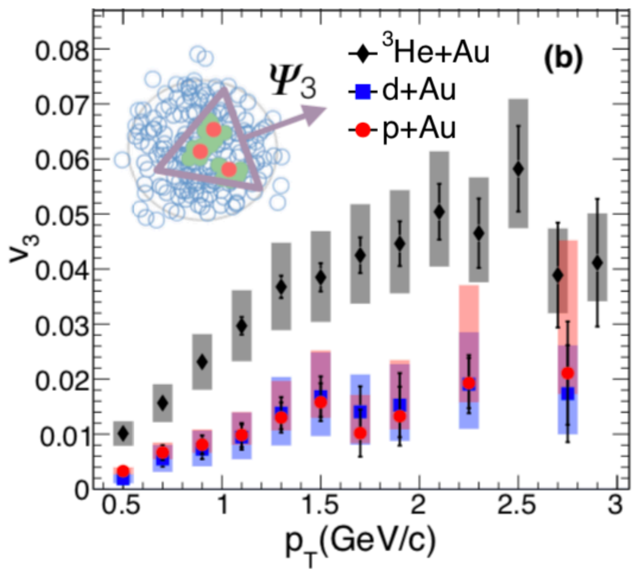
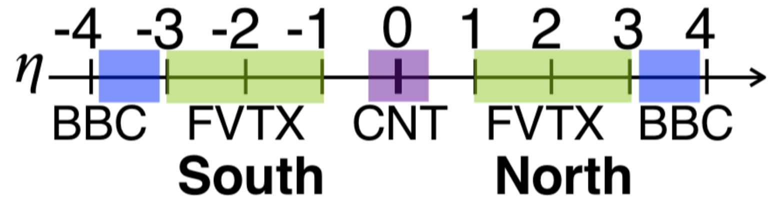
Ready for bulk correlation studies today!!

Key improvements wrt previous scan

Longitudinal dynamics and their impact on the results





$$v_3 = \frac{\langle \cos(3(\phi - \psi_3)) \rangle}{R(\psi_3)}$$

$$R(\psi_3) = \sqrt{\frac{\left\langle \cos 3(\psi_3^{\mathrm{BBCS}} - \psi_3^{\mathrm{FVTXS}}) \right\rangle \left\langle \cos 3(\psi_3^{\mathrm{BBCS}} - \psi_3^{CNT}) \right\rangle}{\left\langle \cos 3(\psi_3^{\mathrm{FVTXS}} - \psi_3^{CNT}) \right\rangle}}$$

Key improvements wrt previous scan

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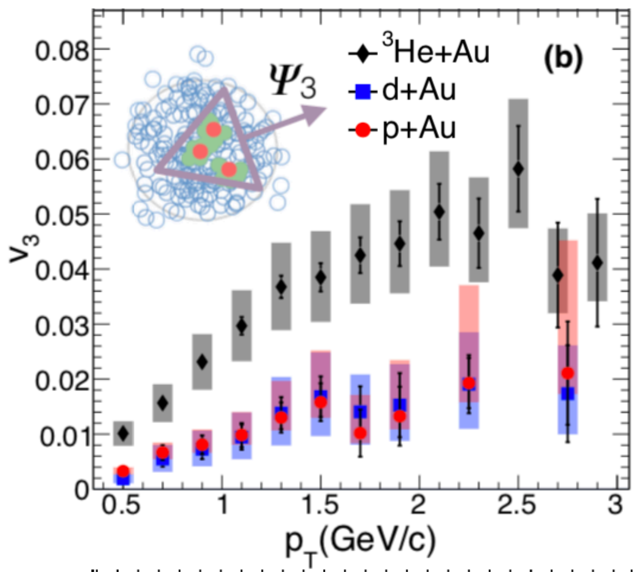

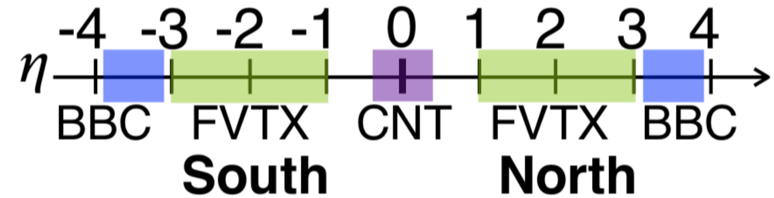

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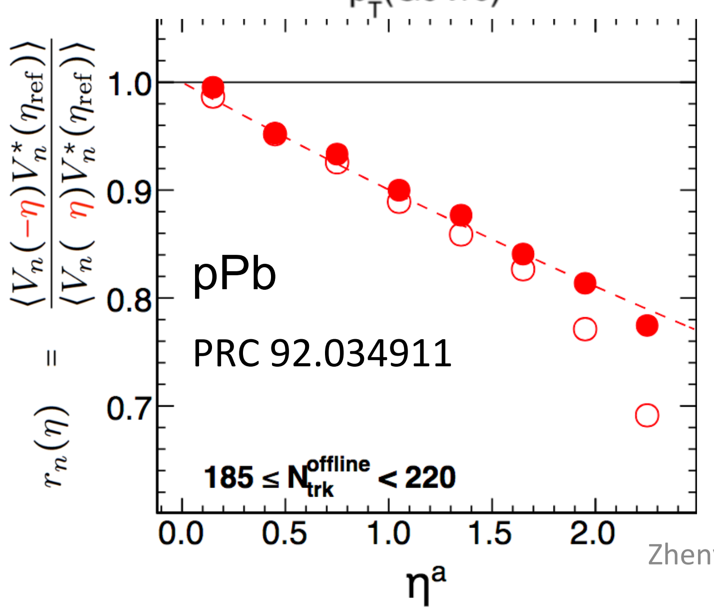


Significant decorrelation effects not considered

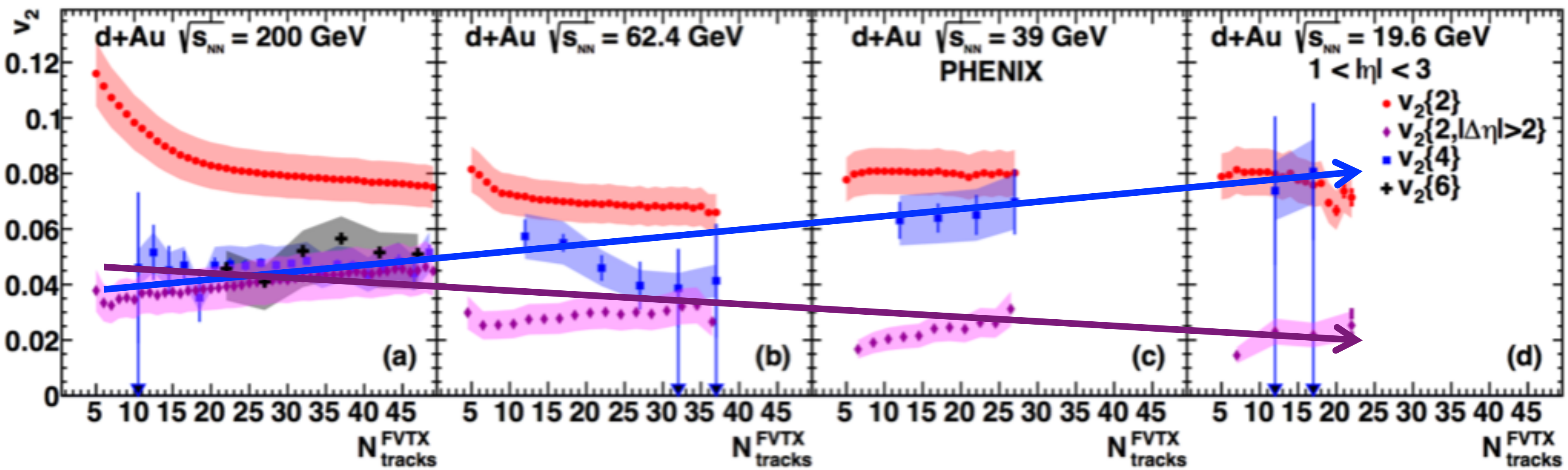
Could be 30% effects assuming scaling by beam rapidity

Key improvements wrt previous scan

Longitudinal dynamics and their impact on the results

Comprehensive studies of multi-particle correlation

PRL 120, 062302 (2018)



Only available in d+Au and hard to interpret

- Non-trivial energy dependence of $v_2\{2\}$ and $v_2\{4\}$
- No pT information for the results

Synergy with LHC

Proposed LHC run schedule

Arxiv.1812.06772

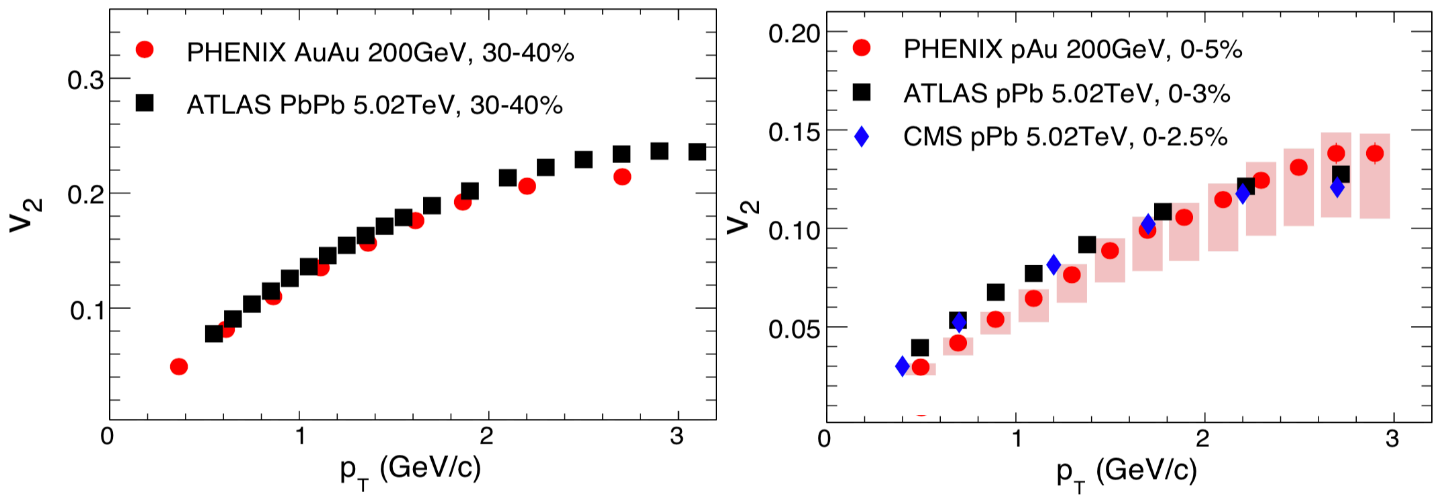
Year	Systems, $\sqrt{s_{NN}}$	Time	L_{int}
2021	Pb–Pb 5.5 TeV	3 weeks	2.3 nb^{-1}
	pp 5.5 TeV	1 week	3 pb^{-1} (ALICE), 300 pb^{-1} (ATLAS, CMS), 25 pb^{-1} (LHCb)
2022	Pb–Pb 5.5 TeV	5 weeks	3.9 nb^{-1}
	O–O, p–O	1 week	500 μb^{-1} and 200 μb^{-1}
2023	p–Pb 8.8 TeV	3 weeks	0.6 pb^{-1} (ATLAS, CMS), 0.3 pb^{-1} (ALICE, LHCb)
	pp 8.8 TeV	few days	1.5 pb^{-1} (ALICE), 100 pb^{-1} (ATLAS, CMS, LHCb)
2027	Pb–Pb 5.5 TeV	5 weeks	3.8 nb^{-1}
	pp 5.5 TeV	1 week	3 pb^{-1} (ALICE), 300 pb^{-1} (ATLAS, CMS), 25 pb^{-1} (LHCb)
2028	p–Pb 8.8 TeV	3 weeks	0.6 pb^{-1} (ATLAS, CMS), 0.3 pb^{-1} (ALICE, LHCb)
	pp 8.8 TeV	few days	1.5 pb^{-1} (ALICE), 100 pb^{-1} (ATLAS, CMS, LHCb)
2029	Pb–Pb 5.5 TeV	4 weeks	3 nb^{-1}
Run-5	Intermediate AA	11 weeks	e.g. Ar–Ar 3–9 pb^{-1} (optimal species to be defined)
	pp reference	1 week	

O+O run at RHIC after BES II is timely for

First comparison between RHIC & LHC with identical Glauber geometry but different sub-nucleon fluctuation (Qs) for a factor of 10 difference in energy

RHIC vs LHC energy comparison

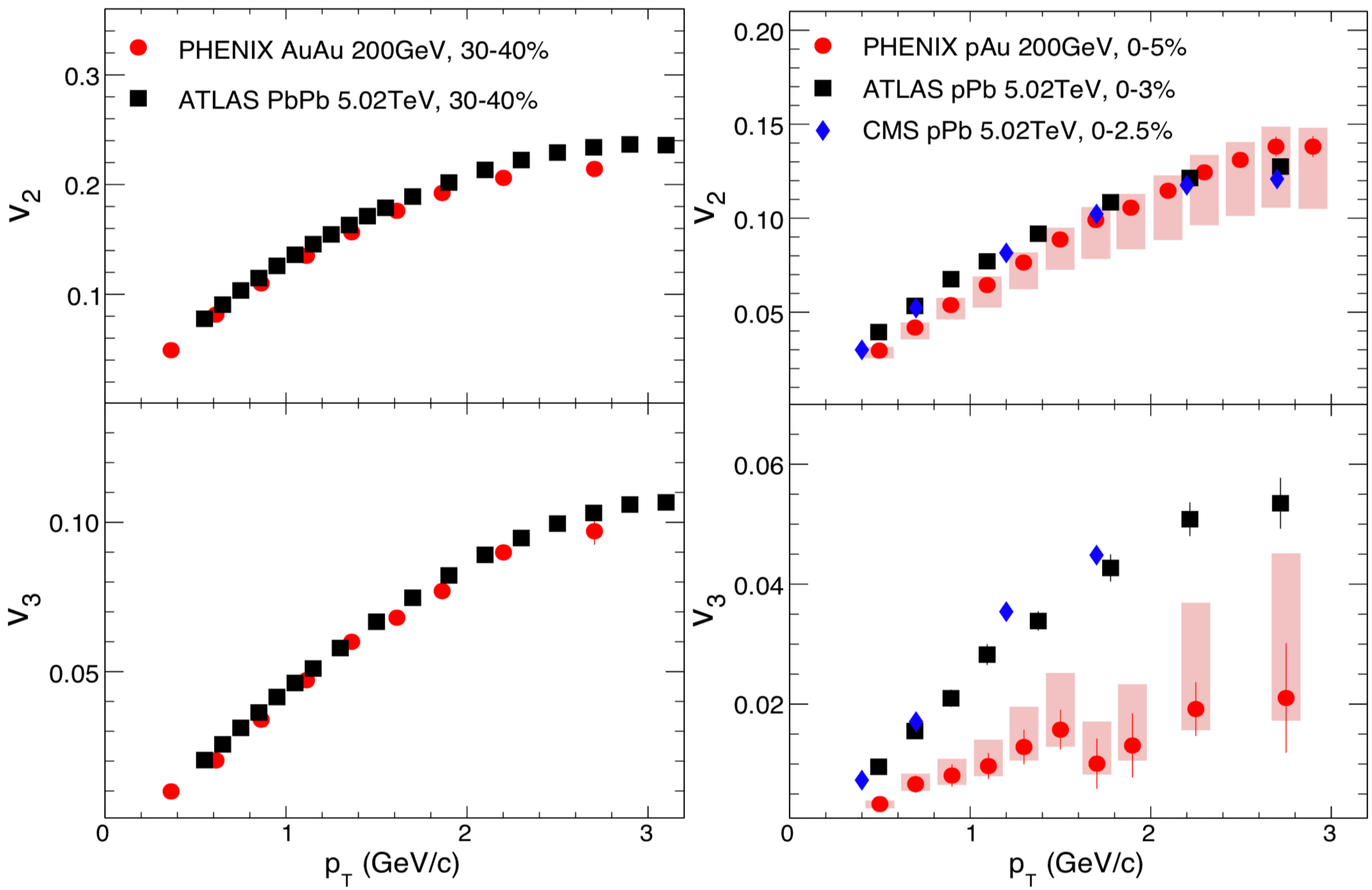
Arxiv.1904.10415



No energy dependence of v_2 in pA vs AA

RHIC vs LHC energy comparison

Arxiv.1904.10415

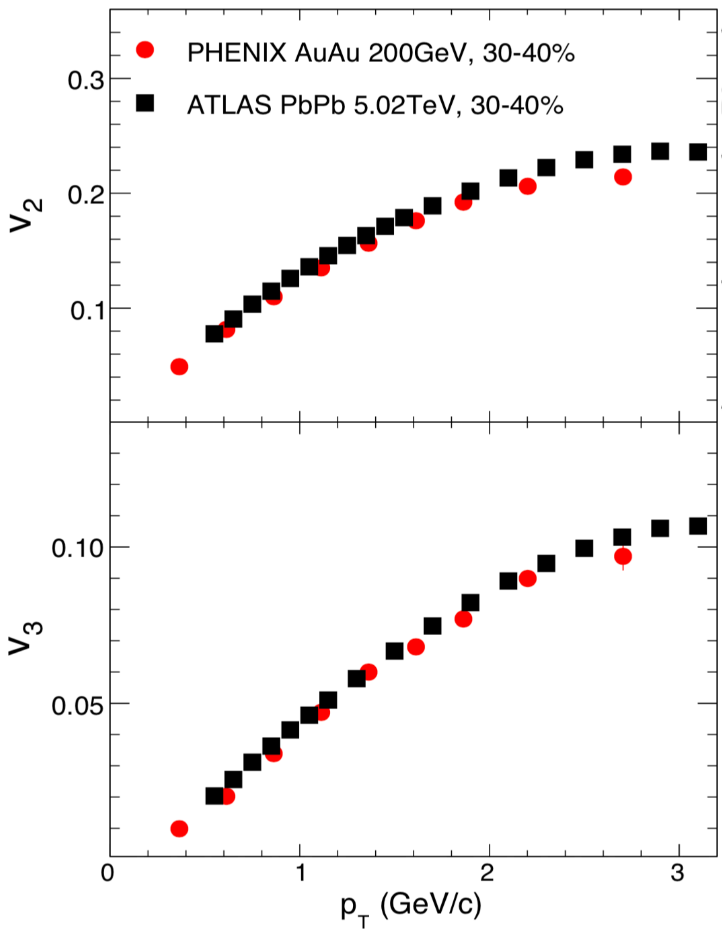


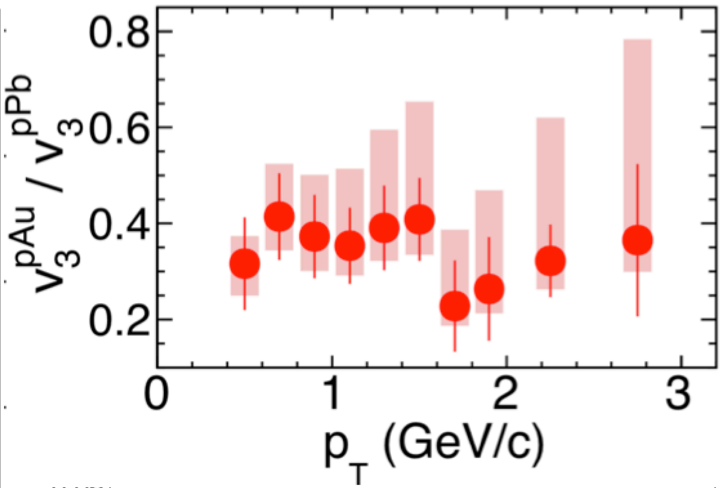
No energy dependence of v_2 in pA vs AA

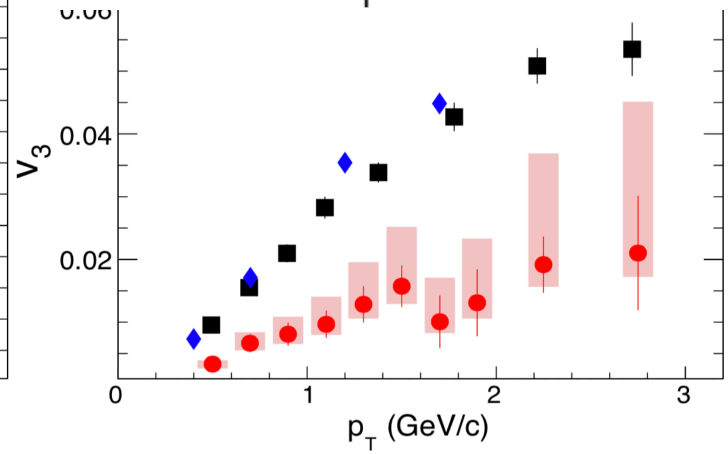
Different energy dependence of v_3 in pA vs AA?

RHIC vs LHC energy comparison

Arxiv.1904.10415







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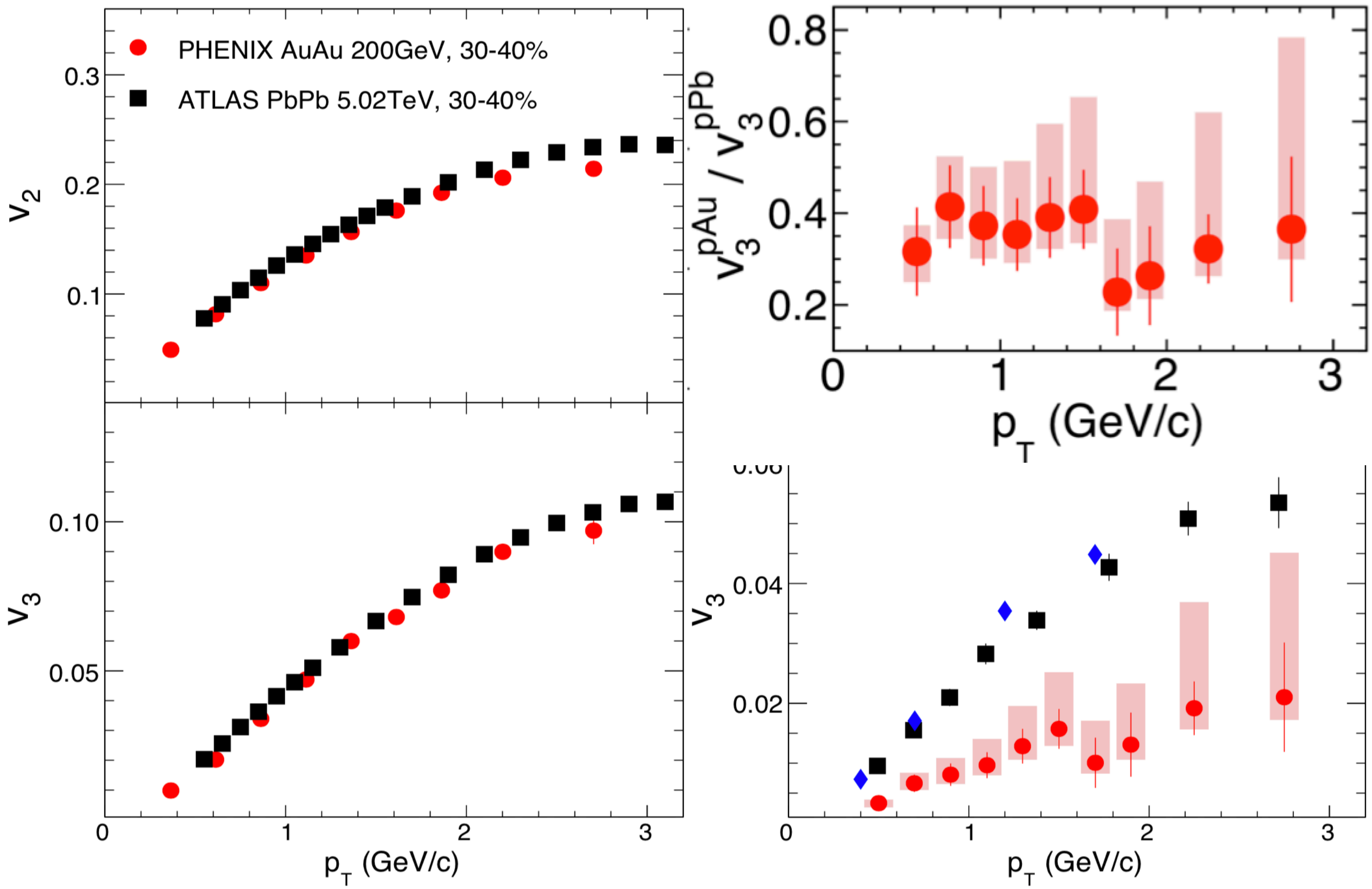


No energy dependence of v_2 in pA vs AA

Different energy dependence of v_3 in pA vs AA?

O+O run at RHIC & LHC can probe the “turn-on”

Full proposal for scan (developing)

Short run of O+O before LHC (2020/2021)

- Synergy with LHC
- Motivate & strengthen future small system scan

Potential trigger commissioning in cold QCD (2022-23)

- Low and high multiplicity triggers at low pile-up
- First “ridge” in 500 GeV pp?

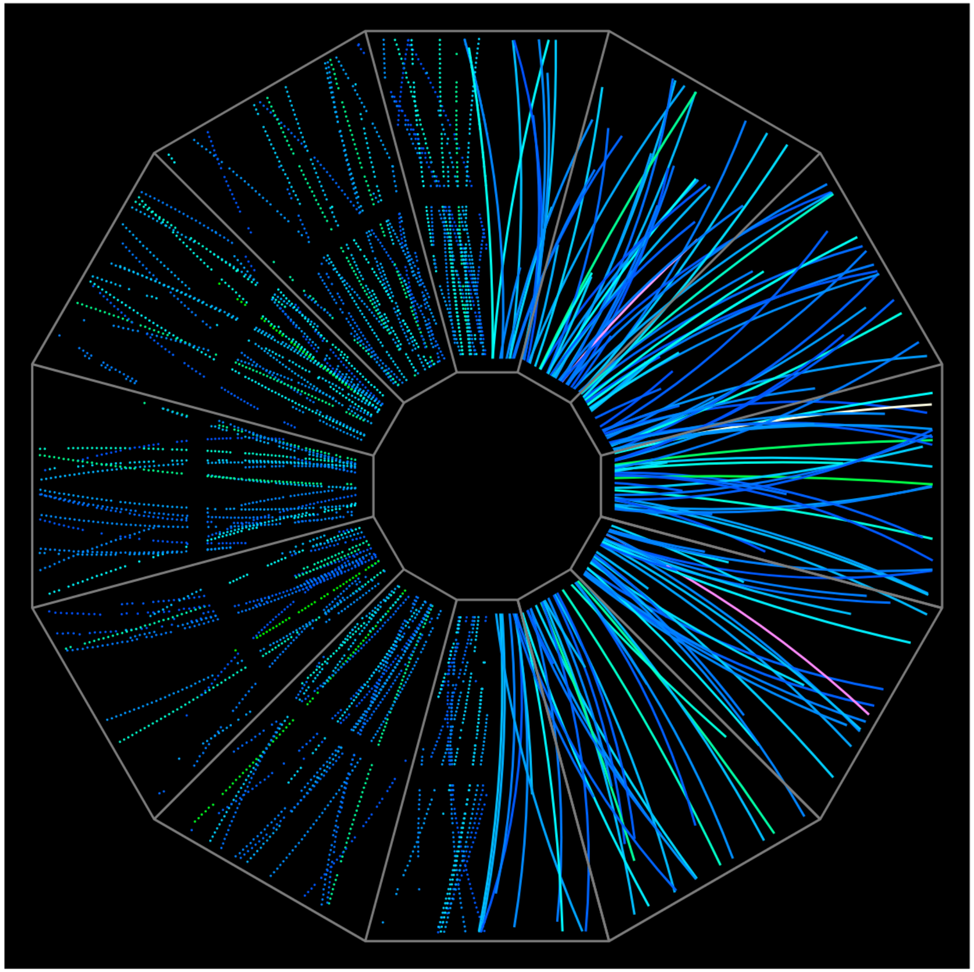
Scan of small asymmetric & symmetric systems (2023+)

- Full benefits from STAR forward upgrade and sPHENIX
- Find the **TRUTH** of collectivity in small systems

STAR proposal for O+O in 2020/2021

The STAR Beam Use Request for Run-20 and Run-21

The STAR Collaboration



May 15, 2019

STAR proposal for O+O in 2020/2021

2020

Single-Beam Energy (GeV/n)	$\sqrt{s_{NN}}$ (GeV)	Run Time	Species	Events (MinBias)	Priority	Sequence
5.75	11.5	9.5 weeks	Au+Au	230M	1	1
4.55	9.1	9.5 weeks	Au+Au	160M	1	3
19.5	6.2 (FXT)	2 days	Au+Au	100M	2	5
13.5	5.2 (FXT)	2 days	Au+Au	100M	2	6
5.75	3.5 (FXT)	2 days	Au+Au	100M	2	2
4.55	3.2 (FXT)	2 days	Au+Au	100M	2	4
3.85	3.0 (FXT)	2 days	Au+Au	100M	2	7
100	200	1 week[2]	O+O	400M 200M (central) (0-5%)	3	8

2021

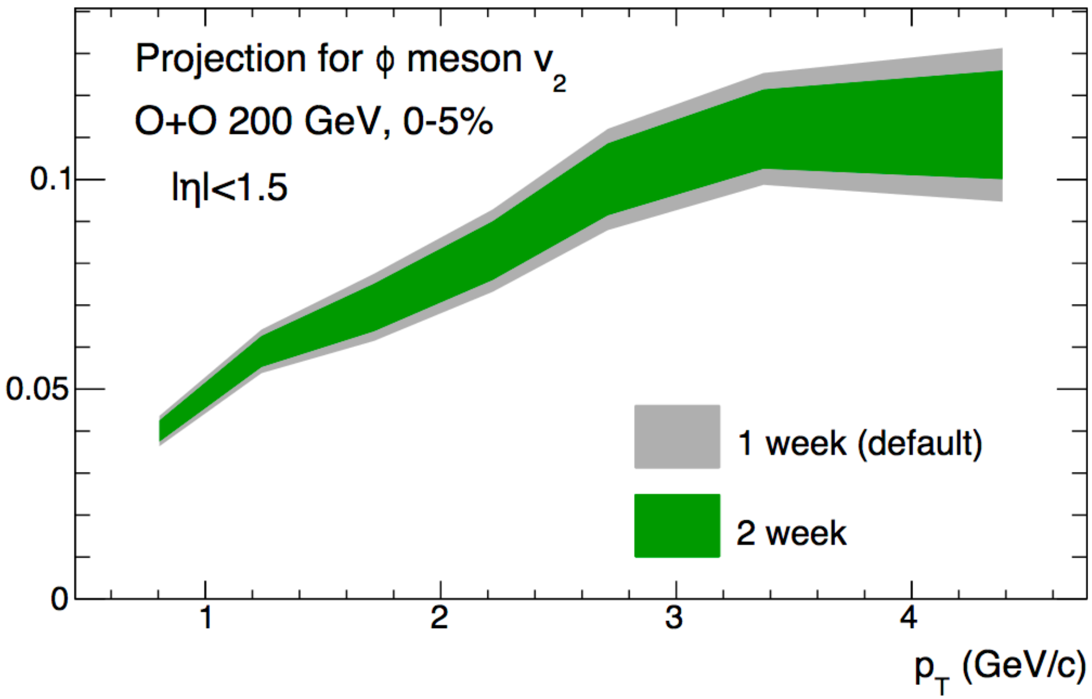
Single-Beam Energy (GeV/n)	$\sqrt{s_{NN}}$ (GeV)	Run Time	Species	Events (MinBias)	Priority	Sequence
3.85	7.7	12 weeks	Au+Au	100M	1	1
8.35	16.7	5 weeks	Au+Au	250M	2	2
100	200	1 week[4]	O+O	400M 200M (central) (0-5%)	2	3

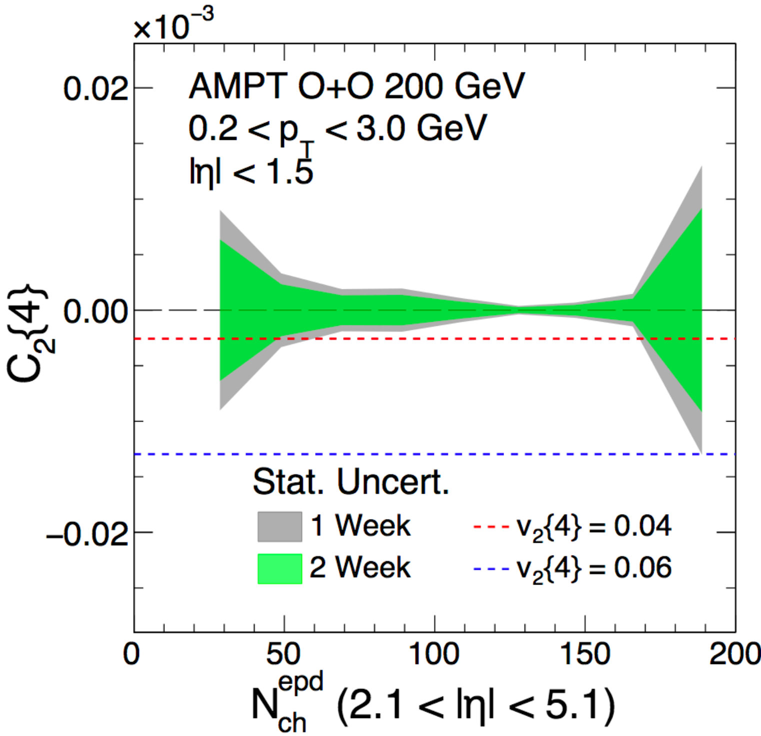
Assuming 20kHz collision rate (low pile-up)

2kHz STAR DAQ rate, 12hr/day

Central trigger based on TPC (|η|<1.5) and/or EPD (2<|η|<5)

Physics potential





Decent measurement of PID flow

Decent measurement of multi-particle correlation

More to come…

Summary

Further understanding of the collectivity in small systems requires disentangling contribution from

- Initial-state interaction
- Non-equilibrium transport
- Fluid dynamics

A scan of small (A)symmetric systems at RHIC will provide unique inputs

- Shape, size, density dependence of collectivity
- Medium property via turn-on of parton-medium interaction

STAR is proposing a short O+O run in 2020/2021 to motivate & strengthen future small system scan

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Further understanding of the collectivity in small systems requires disentangling contribution from

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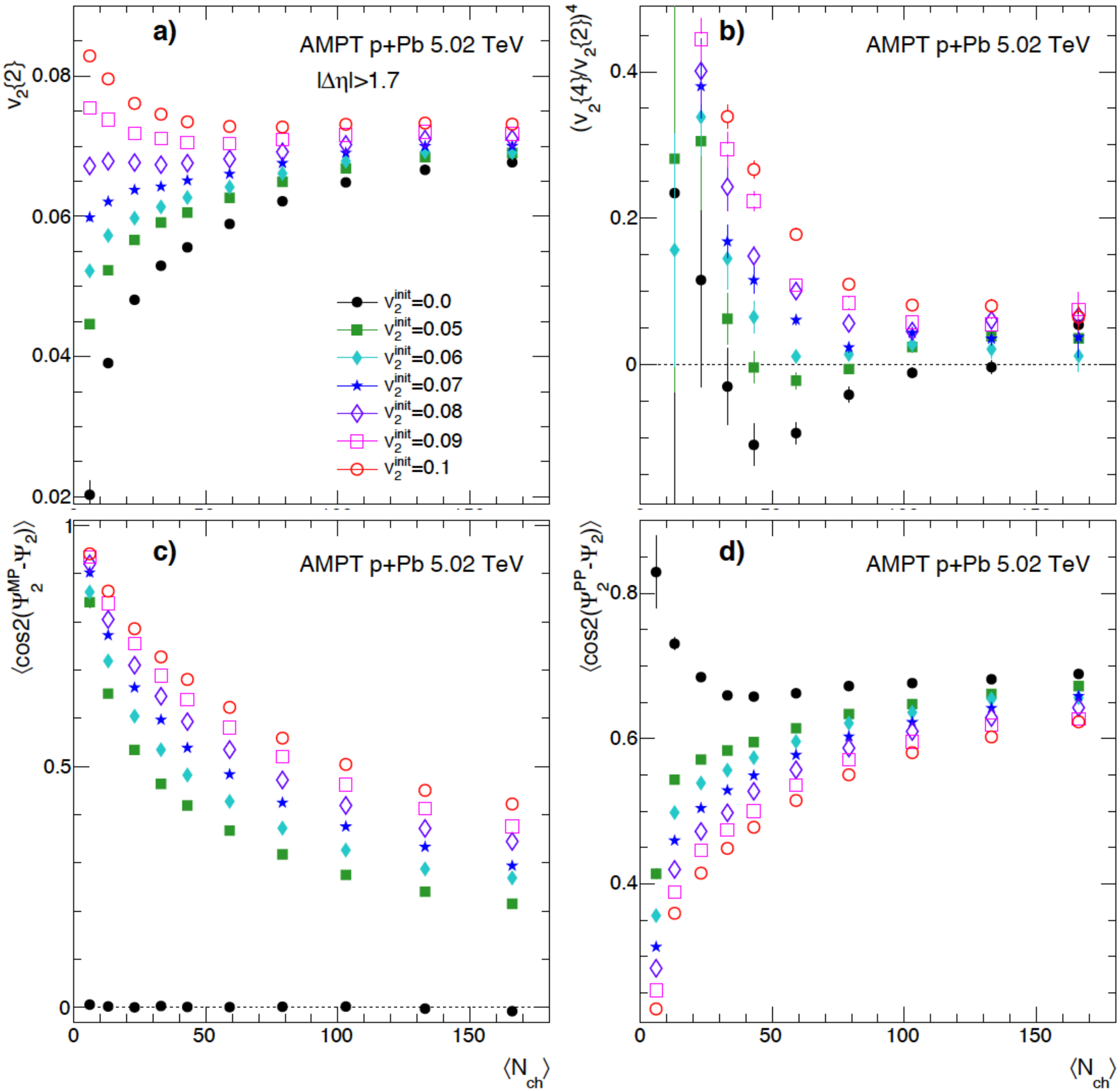
You are welcome to join the effort!!

Back up

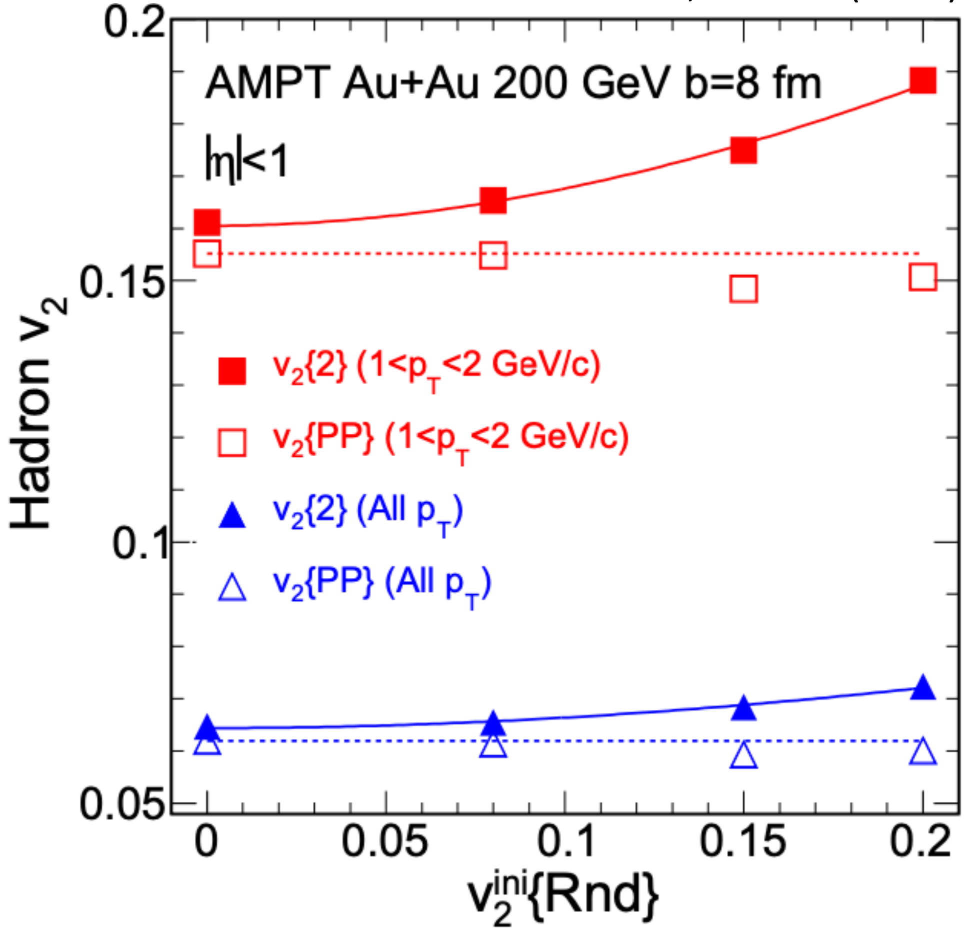
Survivor of initial-state flow

M. Nie, L. Yi, J. Jia, G. Ma
in preparation



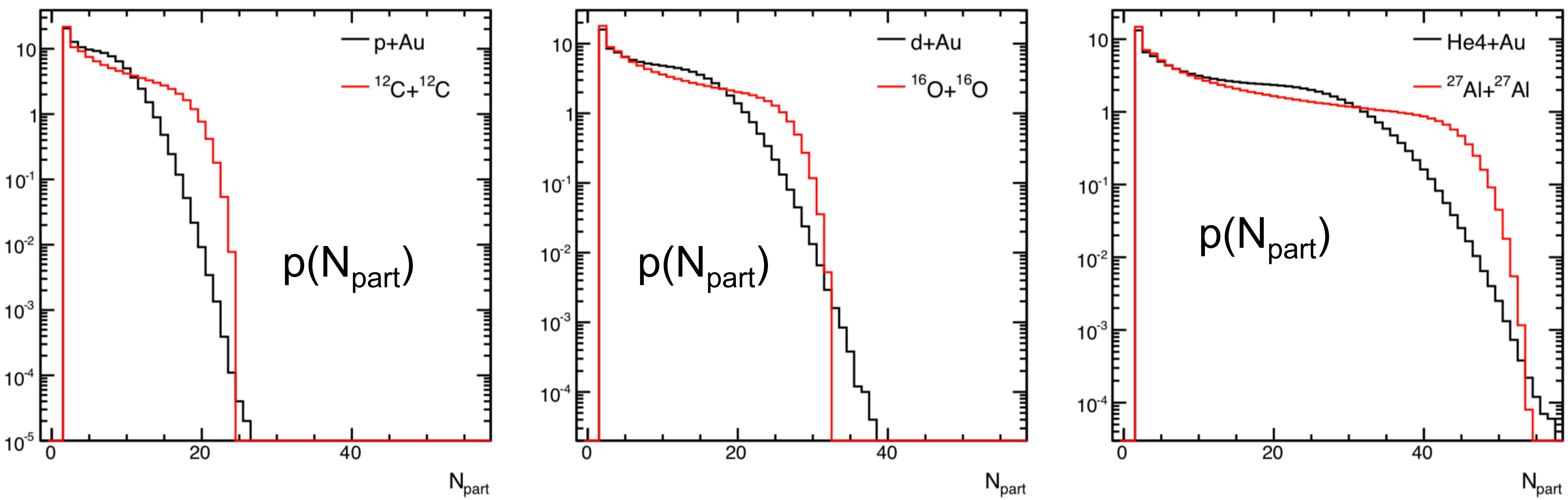
Survivor of initial-state flow

PRC 92, 054906 (2015)



Symmetric vs Asymmetric

Asymmetric system	pAu	dAu	He4Au
$<N_{part}>$	5.8	8.8	13.2
Symmetric system	$^{12}C+^{12}C$	$^{16}O+^{16}O$	$^{27}Al+^{27}Al$
$<N_{part}>$	7.2	9.5	14



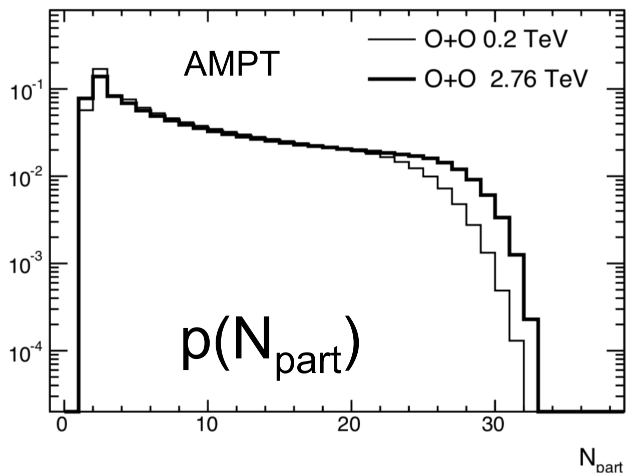
$$p(n_{ch}) = p(N_{part}) \otimes p(n_{ch} | N_{part})$$

- Asymmetric: subnucleon fluctuations more important.
- Symmetric: nucleon fluctuations more important.
  - Less centrality bias & better selection of geometry (N_{part}, ε_n & N_{coll})

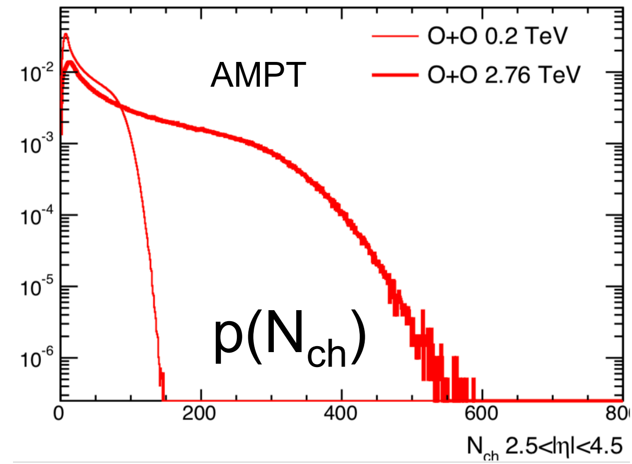
RHIC vs LHC energy-scan

- Similar Glauber geometry but different particle production

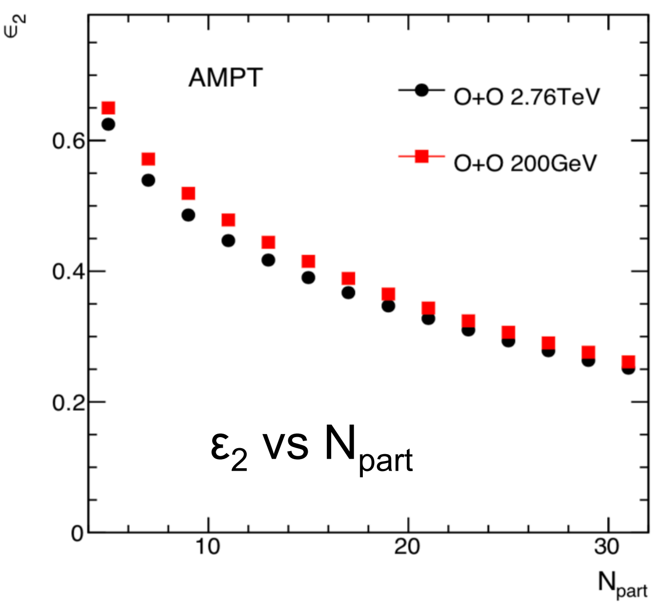
Glauber

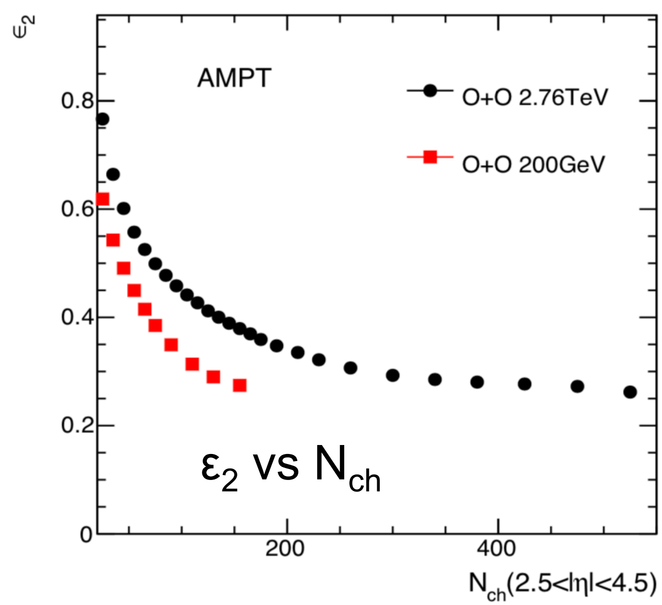


Glauber + fluctuations per nucleon



- Expect larger multiplicity/centrality smearing @LHC





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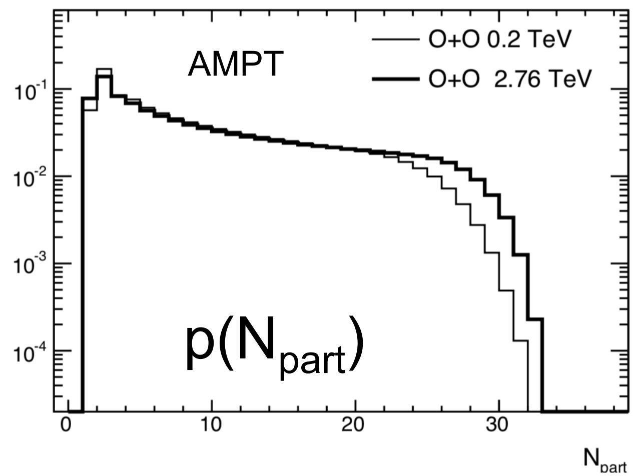
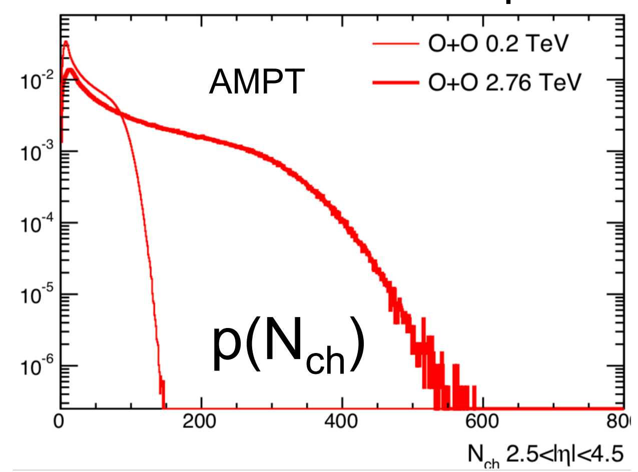


Glauber + fluctuations per nucleon



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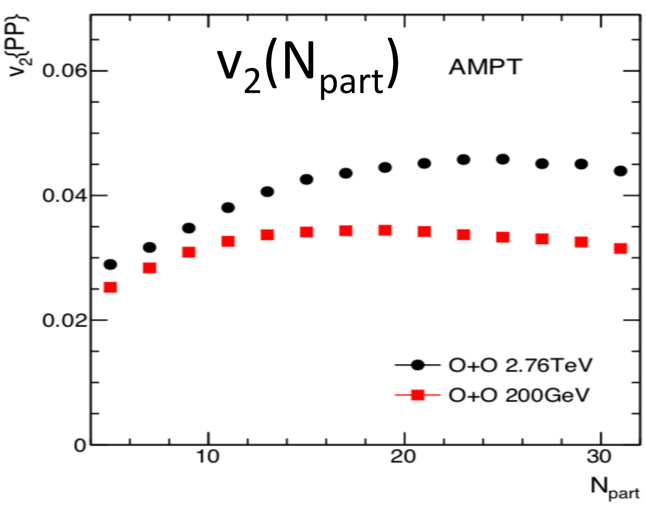
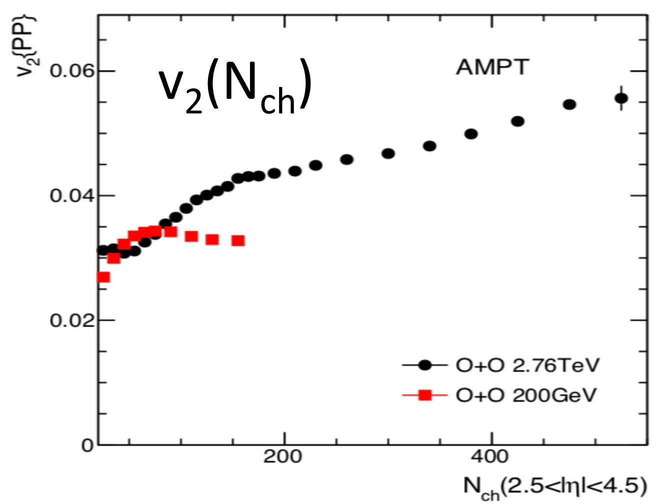


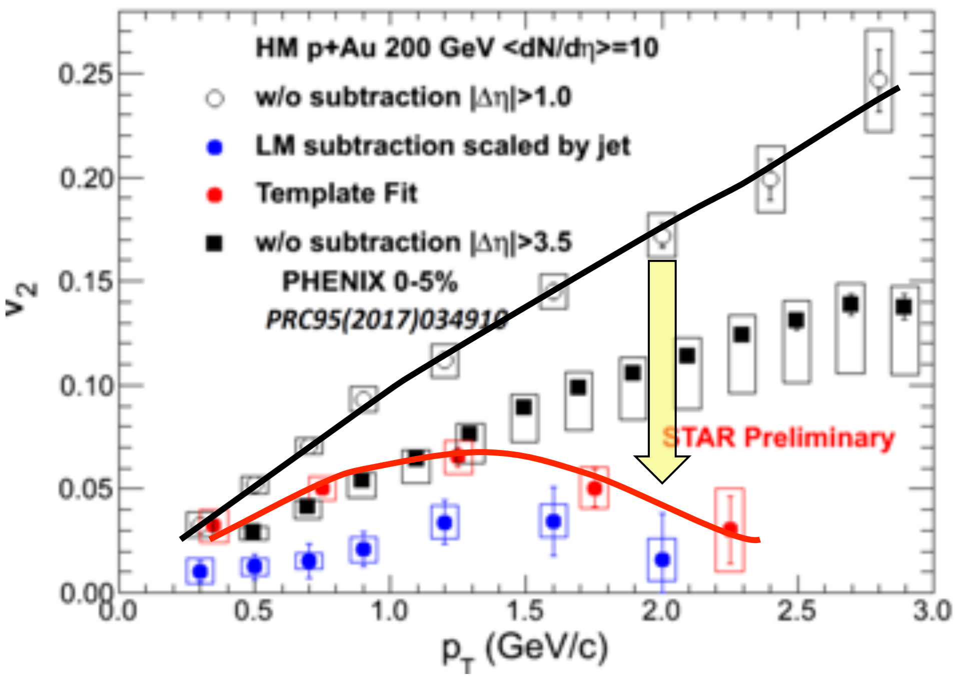
Largely geometry response



N_{ch} smeared by subnucleon/multiplicity fluctuation at larger √s

Non-flow systematics

- STAR: Subtraction significantly reduces non-flow, but may lead to over-subtraction at high p_T (1902.11290)
- PHENIX: pAu non-flow could still be large.
  - Non-flow is smaller than STAR w/o subtraction, but not shown whether it is smaller than STAR w/ subtraction.
  - Closure test need to be done for PHENIX kinematics for a fair conclusion.



S. Lim, Q. Hu, R. Belmont, K.Hill, J.Nagle, D. Perepelitsa 1902.11290